

Advances in Manufacturing Technology XXVII

Cranfield
UNIVERSITY

Proceedings of the 11th International Conference on Manufacturing Research

Incorporating the 28th National Conference on
Manufacturing Research

Essam Shehab. Peter Ball. Benny Tjahjono
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Dr Essam Shehab, Dr Peter Ball and Dr Benny Tjahjono

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Foreword

The International Conference on Manufacturing Research is a major event for academics and industrialists engaged in manufacturing research. Held annually in the UK since the late 1970s, the conference is renowned as a friendly and inclusive environment that brings together a broad community of researchers who share a common goal; developing and managing the technologies and operations that are key to sustaining the success of manufacturing businesses.

For over two decades, ICMR has been the main manufacturing research conference organised in the UK, successfully bringing researchers, academics and industrialists together to share their knowledge and experiences. Initiated a National Conference by the Consortium of UK University Manufacturing Engineering Heads (COMEH), it became an International Conference in 2003.

COMEH is an independent body established in 1978. Its main aim is to promote manufacturing engineering education, training and research. To achieve this, the Consortium maintains a close liaison with government bodies concerned with the training and continuing development of professional engineers, while responding to the appropriate consultative and discussion documents and other initiatives. COMEH is represented on the Engineering Professor's council (EPC) and it organises and supports national manufacturing engineering education research conferences and symposia.

The host universities for National Conference on Manufacturing Research (NCMR) have been:

1985	Nottingham	1994	Loughborough
1986	Napier	1995	De Montfort
1987	Nottingham	1996	Bath
1988	Sheffield	1997	Glasgow Caledonian
1989	Huddersfield	1998	Derby
1990	-	1999	Bath
1991	Hatfield	2000	East London
1992	Central England	2001	Cardiff
1993	Bath	2002	Leeds Metropolitan

In 2002 the conference was accorded the title International (ICMR) to reflect the current trends in manufacturing engineering and to promote the exchange of research and engineering application experiences internationally. The ICMR, has since its introduction, incorporated the NCMR. The 11th ICMR incorporates the 28th NCMR. The host universities for ICMR have been:

2003	Strathclyde	2009	Warwick
2004	Sheffield Hallam	2010	Durham
2005	Cranfield	2011	Glasgow Caledonian
2006	Liverpool John Moores	2012	Aston
2007	De Montfort	2013	Cranfield
2008	Brunel		

Acknowledgements

On behalf of the ICMR2013 organising committee, first and foremost we would like to thank COMEH for inviting Cranfield University, once again, to host the ICMR2013. We would also like to take the opportunity to thank all of the contributing authors for their high quality of papers submitted, the reviewers for their time and constructive comments, the keynote speakers for sharing their experiences to the delegates and the local organising committee for their meticulous preparation of the conference.

Special thanks go to Kostas Salonitis and Isaac Sanya for their help in editing the papers. Last but certainly not least, we are most grateful with the administrative support provided by Ellie Collins and Teresa Bandee.

This year, ICMR2013 takes place on the 19-20 September 2013 at Cranfield University. The conference focuses on any aspects of product development, manufacturing technology, manufacturing systems, information systems and digital technologies. It provides an excellent avenue for researchers to present state-of-the-art multidisciplinary manufacturing research and exchange ideas. In addition to the 4 keynote speeches and 3 invited presentations, there are 107 papers in these proceedings. These papers are split into 24 technical sessions.

We look forward to welcoming you to an exciting and lively conference!

Essam Shehab, Peter Ball and Benny Tjahjono
Editors

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Design Process and Methods

CAPTURING THE INDUSTRIAL REQUIREMENTS OF SET-BASED DESIGN FOR CONGA FRAMEWORK

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ABSTRACT

The Configuration Optimisation of Next-Generation Aircraft (CONGA) is a proposed framework in a response industrial need to enhance the aerospace capability in the UK. In order to successfully address this challenge, a need to develop a true multi-disciplinary Set-Based Design (SBD) capability that could deploy new technologies on novel configurations more quickly and with greater confidence was identified. This paper presents the first step towards the development of the SBD capabilities which is to elicit the industrial requirement of the SBD process for the key aerospace industrial partners involved in this CONGA approach.

Keywords: LeanPPD, Set-Based Concurrent Engineering, Aerospace Industrial requirements.

1 INTRODUCTION

Several UK aerospace companies have identified a need for a new multi-disciplinary design and integration process to support the conceptual design and assessment of future aircraft configurations. A new project named 'Configuration Optimisation of Next-Generation Aircraft' (CONGA) has been launched as a response to this need. Together with three aerospace companies and support of Technology Strategy Board (TSB) this project aims to develop a selection of innovative capabilities to meet the future products needs by enhancing companies' Product Development (PD) processes. Set-Based Design (SBD) based on the lean principles has been identified as a suitable approach to satisfy the aforementioned industrial needs. However these needs have to be thoroughly understood, well classified and commonly agreed. This paper is presenting the research done in order to capture and analyse the industrial requirements of the Set-Based Design approach for the CONGA project.

There is an interchangeable use of the term SBCE and SBD loosely allowed in this research perspective although the difference exists.

2 RESEARCH METHODOLOGY

The research methodology is sectioned in three phases, including:

1. **CONGA foundation** – The extensive literature review has been conducted and a field study where the companies' current LeanPD practice was assessed and analysed was carried out.
2. **Industrial requirement elicitation** – The questionnaire and a template have been created and later used in a series of semi-structured interviews and workshops where the requirements have

been elicited. The collected requirements were then analysed and several diagrams were produced for visual representation of the results.

3. **Requirements validation** – The results of the analysis of SBD industrial requirements have been validated by CONGA industrial partners and a common agreement about their importance has been achieved.

3 RELATED LITERATURE

Khan (2012) developed a comprehensive model that outlines the enablers of Lean Product Development. The Lean Product and Process Development (LeanPPD) model focuses on value creation, provision of knowledge environment, continuous improvement and it represents a process that encourage innovation and collaboration. Set-Based Concurrent Engineering (SBCE) is considered a main enabler of LeanPPD and it characterises a strategic and convergent product development (PD) process guided by consistent technical leadership throughout. Therefore, SBCE enables the focus on the value and continuous improvement within the industrial design and manufacturing outfit (Khan, 2012). Sobek *et al.* (1999) developed a framework based on a case study of the Toyota PD system in which they identify 3 broad principles of SBCE: (1) Map the design space, (2) Integrate by intersection and (3) Establish feasibility before commitment. SBCE could be defined as the process where “Design engineers practice SBCE by reasoning, developing, and communicating about the set of solutions in a concurrent manner. As the design progresses, they were gradually narrow, their respective sets of solutions based on the understanding gained through their communication. As they were narrow, they commit to staying within the sets so that others can rely on their communication” (Sobek *et al.* 1999). It is therefore believed that, this methodology can positively impact development time, product cost and product quality (Al-Ashaab *et al.* 2013). The aforementioned principles are not a standard procedure that has to be applied step by step, but are generic principles that can be applied differently depending on the nature of the project. In their extensive research Khan *et al.* (2011) identified and collected the SBCE principles which have been then classified into five categories. Two new categories have been introduced as an extension of the initial set of principles proposed by Sobek *et al.* (1999). These principles have been then converted to a new SBCE baseline model shown in Figure 1 which clearly defines the PD stages and their corresponding activities.

1. Define Value	2. Map Design Space	3. Develop Concept Sets	4. Converge on System	5. Detailed Design
1.1 Classify projects	2.1 Decide on level of innovation to sub-systems	3.1 Extract (pull) design concepts	4.1 Determine intersections of sets	5.1 Release final specification
1.2 Explore customer value	2.2 Identify sub-system targets	3.2 Create sets for sub-systems	4.2 Explore possible product system designs	5.2 Manufacturing provides tolerances
1.3 Align project with company strategy	2.3 Define feasible regions of design space	3.3 Explore sub-system sets: simulate, prototype & test	4.3 Seek conceptual robustness	5.3 Full system definition
1.4 Translate value to designers (via product definition)		3.4 Capture knowledge and evaluate	4.4 Evaluate possible systems for lean production	
		3.5 Communicate sets to others	4.5 Begin process planning for manufacturing	
			4.6 Converge on final system	

Figure 1: SBCE Baseline Model: Activity View

4 INDUSTRIAL REQUIREMENT ELICITATION PROCESS

Through the extensive literature review, a good understanding of the SBCE principles has been developed. This understanding, together with the background knowledge from LeanPPD project enabled the development of the requirements statements for the CONGA Set-Based Design (SBD) process. Twenty-eight (28) statements have been developed based on the SBD principles and taking into account the elements which will characterize the CONGA-SBD process model: (1) Process simplification, (2) Knowledge-Based Environment, (3) supply chain collaboration, and (4) collaborative IS framework.

To identify if the SBCE principles can address and satisfy the current PD issues of the CONGA partners, a semi structured questionnaire was developed. Questionnaire incorporated the requirements

statements in a way that the right information was elicited through a series of face-to-face interviews, webex sessions and workshops. Figure 2 illustrates the process followed to elicit the industrial requirements.

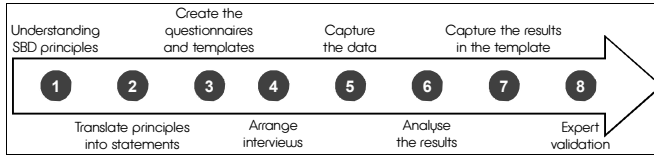


Figure 2: Industrial requirements elicitation process.

The next section presents the methodology for the development of SBD industrial requirements.

5 SET-BASED DESIGN INDUSTRIAL REQUIREMENT

In order to develop effective industrial requirements, each statement is based on the SBCE principles. Therefore, this step was crucial because it guaranteed a solid foundation for the industrial requirements' elicitation and then for the future SBD model proposed. It is also very important to highlight that, the statements have been organised by following the logic of the SBCE Baseline Model shown in Figure 1 to design a document that follows a clear logic and also facilitates successful industrial interviews performing. Table 2 below, shows examples of how the captured principles have been converted into statements to elicit the SBD industrial requirements.

Table 1: SBCE Principles and relative statements for the SBD process model.

SBCE Principles	Relative industrial requirements statement
Classify projects into a project portfolio	The SBD process model shall support the company's project classification process (the project duration, intended market, risk, budget, man/month effort, level of innovation, etc.) and make it smoother, rapid and cost effective. Everyone involved throughout the design process should have a clear understanding of the features that characterize each project since the early stage.
Define feasible regions based on knowledge, experience and the chief engineer, and consider the different functional groups	The SBD process model shall support the identification of feasible possibilities of the alternative design solutions based on: knowledge, experiences, previous projects, and new innovative ideas. At the same time, considering constrains of different functional groups.
Ensure many possible subsystem combinations to reduce the risk of failure	The SBD process model shall provide the mechanism that would aid designers to create alternative solutions for each subsystem, avoiding design rework and reducing cost and time.
Perform aggressive evaluation of design alternatives to increase knowledge and rule out weak alternatives	The SBD process model shall facilitate activities to aggressively narrow down the set of solutions into a reasonable number to be developed. This is also analysed based on certain criteria that address the identified value attributes.

Figure 3 presents an example of the structure for requirements statement s in the questionnaire.

REQUIREMENT 11.						
The SBD process model shall facilitate the extraction and the pull of the existing design concepts from previous projects, research and development, competitors, and other internal documents.						
	Not important	Not very important	Somewhat important	Important	Very important	Not applicable
a) RELEVANCE	☐	☐	☐	☐	☐	☐
b) FEASIBILITY	☐	☐	☐	☐	☐	☐
c) Constrains						
d) Other comments & suggestions:						

Figure 3: Example of the structure of the questionnaire template

The terms used to assess the requirement are:

1. **Relevance:** It refers to the importance of the requirements to establish the SBD capabilities. Scale used to measure the relevance has five levels: From 1 (not important) to 5 (very important). The value 0 represents that the requirement is not applicable.
2. **Feasibility:** It refers to the likelihood to introduce and implement the requirement in the company. Scale used to measure the relevance has five levels: From 1 (not easy at all) to 5 (very easy). The value 0 represents that the requirement is not applicable.
3. **Constraints:** It refers to the factors that will hinder or have a negative impact on the implementation of the requirements to the development of the CONGA enablers.
4. **Other comments & suggestions:** Space left for the interviewee to provide ideas, suggestions or comments.

Relevance and Feasibility were used in order to identify the requirements with the highest importance and likelihood. It is expected that this requirements will guide the CONGA SBD process development.

6 FINDINGS AND DISCUSSION

During the analysis and validation of the produced requirements statements with the industrial partners, it was observed that, some of the input capabilities of the model would not have addressed any of the possibility improvements, therefore this statements were removed from the questionnaire.

The research findings, however, guaranteed that, in the final version of the questionnaire, there were only statements related to the model's actual capabilities and therefore, able to address the issues affecting the PD process of the CONGA industrial partners. Many statements turned out to be capable of addressing more than one issue, which is a positive impact.

As described in Section 4, the industrial requirements were elicited through a series of face-to-face interviews, webex sessions and workshops in total duration of over 44 hours. It must be emphasised that interviewees were mostly the designers and engineers from different working functions; therefore they presented a multitude of real users of the PD processes.

The collected data was organised in a specifically for this purpose developed excel template shown in Figure 4 and in this paper referred to as an 'Industrial Requirements Report' which tremendously simplified the results analysis. The average result from the scores given by the interviewees was calculated for each of the requirements statement as shown in Figure 4. Furthermore, all further constraints, comments and suggestions given by interviewees were also noted and captured in the report, however due to company specific comments these are not shown in Figure 4.

The Relevance-Feasibility matrix shown in Figure 5 was then created from the calculated average results which are presented in Figure 4. Figure 5 illustrates the resultant matrix has where the 'relevance' is shown on the X-axis and the 'feasibility' on the Y-axis. Furthermore, each of the CONGA industrial partners is coded with a different symbol in order to distinguish the authorship of the requirement. Moreover, each of the symbols has allocated number where each one represents a requirement from the industrial requirement report. For example, Company 1 scored an average of 4.8 in Relevance and 2.1 in Feasibility and Company 2 scored an average of 5 in Relevance and 1.8 in Feasibility for the requirement statement number 13 which says: *"The SBD process model shall provide the mechanism that would aid designers to create alternative solutions for each subsystem, avoiding design rework and reducing cost and time"*. The data in the matrix (Figure 4) nor in the report (Figure 5) do not represent the real results from the analysis due to confidentiality reasons.

Questions	Industrial Requirements is a statement that identifies a necessary capability, characteristic, or quality factor of the process model in order to have value and utility for the users.	RELEVANCE (1 - not important to 5 - very important, 0 - not applicable)		FEASIBILITY (1 - not easy at all to 5 - very easy, 0 - not applicable)	
		COMPANY 1	COMPANY 2	COMPANY 1	COMPANY 2
The SBD model : Ind.Reg.1 - CUSTOMER VALUE, PD and BUSINESS STRATEGY, PRODUCT FUNCTIONALITY					
1	The SBD process model shall support the company's project classification process and make it smoother, rapid and cost effective. Everyone involved in the design process should have a clear understanding of the features that characterize each project since the early stage.	4.5	4.0	3.0	2.5
4	The SBD process model shall enable the filtering/ranking of the value into key/essential value with agreed targets.	5.0	4.0	3.6	3.5
9	The SBD process model shall associate the keyvalue with product functionalities and provide a mechanism for several simulations to provide alternative concepts.	4.3	4.7	3.0	2.8
The SBD model: Ind.Reg.3 - CREATION AND ANALYSIS OF SETS OF ALTERNATIVE SOLUTIONS					
12	The SBD process model shall facilitate the extraction and the pull of the existing design concepts from previous projects, research and development, competitions and other internal documents.	4.6	4.5	3.1	2.5
13	The SBD process model shall provide the mechanism that would aid designers to create alternative solutions for each subsystem, avoiding design rework and reducing cost and time.	4.8	4.4	3.3	1.8
14	The SBD process model shall provide a suitable environment and tools to stimulate the creation of sets of alternative subsystem solutions and encourage innovation.	4.3	3.9	2.9	2.1
17	The SBD process model shall facilitate an activity to explore the intersections of the feasible sets of alternative subsystem solutions and evaluate them against certain criteria that addresses the identified value attributes.	5.0	4.8	2.8	3.2
The SBD model :Ind.Reg.4 : CONVERGE TO THE FINAL SYSTEM SOLUTION					
18	The SBD process model shall facilitate activities to aggressively narrow the set of solutions into a reasonable number to be developed and analyzed based on certain criteria that addresses the identified value attributes	4.5	4.2	3.3	3.4
19	The SBD process model shall facilitate the mechanism to store the unfeasible (ruled-out) solutions for consideration in the future projects	4.2	4.8	3.1	2.0

Figure 4: Example SBD industrial requirements report

The importance of the 'relevance-feasibility matrix' shown in Figure 5 is essential at this stage to enhance and simplify the mapping as it presents the results from the industrial requirements' elicitation process in a visual manner.

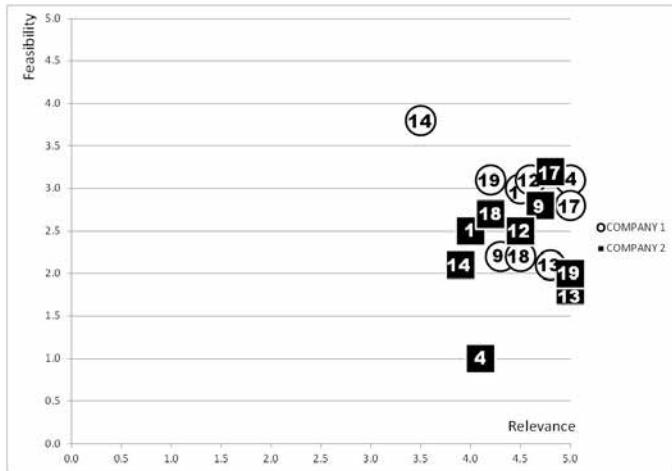


Figure 5: Example of Relevance-Feasibility Matrix

This matrix has also helped to compare the scores of the different industrial requirements within the company as well as comparing them among the CONGA industrial partners. Figure 5 shows that most of the requirements scored very high on the relevance axis and medium on the feasibility axis.

Therefore, the main outcome of the relevance-feasibility matrix is the identification of the recognizable need for the development of the SBD process. At the same time this matrix is outlining the challenges for the implementation of the SBD principles. However, due to the novelty of the research, it was expected that the feasibility will be medium to low.

The resulting report together with the relevance-feasibility matrixes has been passed to the CONGA industrial partners for the initial validation and a joint workshop with CONGA industrial partners has been organised, where the list of 28 SBD industrial requirements has been grouped and reduced to 10 more generic requirements with the highest importance. Moreover, this list of the 10 SBD requirements has been mapped against several issues currently existing in the product development processes of the CONGA industrial partners and future steps has been decided. This is implying that the initial set of SBD requirements was a good representation of the industrial needs and the research undertaken presents a good starting point for the development of new SBD process model.

7 CONCLUSION

This paper presented a research where the industrial requirements of Set-Based Design (SBD) for CONGA framework have been elicited. For that purpose a questionnaire with 28 requirement statements which are based on the SBCE principles has been developed. The constraints, other comments and suggestions captured in the questionnaires for each requirement also describe some expected challenges for requirements introduction and implementation into the companies involved.

Captured industrial requirements are expected to evolve during the research and more details will be recognised, however, they will not change or deviate significantly. It is felt that developed industrial requirements are presenting a good answer to the existing product development challenges and issues faced by CONGA industrial partners and that they provide a sufficient foundation to actually develop the CONGA framework enablers for the Set-Based Design (SBD) approach.

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BUILDING CREATIVE CONFIDENCE IN IDEA MANAGEMENT PROCESSES TO IMPROVE IDEA GENERATION IN NEW PRODUCT DEVELOPMENT TEAMS

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ABSTRACT

This is a scoping paper that aims to establish effective practices and key players in the domain of Idea Management. The paper defines Idea Management as the generation, evaluation and selection of ideas. The purpose of the paper is to map the current landscape of methodologies and tools in order to identify gaps and support the development of a framework to enhance creative confidence in idea management. The study has two key research questions: (i) what factors are influencing current idea generation practices and (ii) what tools and approaches exist for idea generation. This will help identify how creative confidence can influence the idea generation processes. Creative confidence is the capability to come up with breakthrough ideas, associated with the bravery to perform. If stimulated in the right way with a valuable framework, its impact on employees' performance is significant in improving team members' innovation performance and quality of ideas.

Keywords: creative confidence, idea management, creative performance.

1 INTRODUCTION

Bono (2007) identifies two current issues in innovation and new product development departments. The first one is that the access to data and information has become a commodity available to every organisation, so it is not a competitive advantage anymore. The second one is that, consequently, ideas are the trigger for innovation and without innovation companies won't succeed. The first research question that this paper addresses in current literature is idea generation practices and explores emerging concepts such as creative confidence, performance and productivity to help generate strategies and conditions for improving collective creativity (Kao, 1996)

The purpose of this study is to identify strategies that can help build creative confidence in NPD teams and impact on their performance of idea generation. The methodology used will be a systematic literature review along with the analysis of data gathered.

The second key question is addressed by identifying tools and frameworks to build a robust idea generation process that brings together research concepts and activities relating ideation and creativity and how to manage the idea generation more effectively.

The literature reviewed 88 papers from internationally known journals using three databases: Scopus, EBSCO, and Web of Knowledge. A thematic coding analysis (Robson, 2011) was used as well as by keyword search strings.

This paper will add value and contribute new knowledge through exploring (Levitt, 1963) the established problem associated with the lack of conversion of ideas into actual innovations, through testing frameworks to prove how they can improve the ability of teams to generate better quality ideas. Current idea management processes include diverse approaches to generate, select and evaluate ideas, but there is not a clear set of practices to improve employees' performance, which is addressed just from a psychological and social point of view with no clear tools or methodologies to enhance their performance and productivity. The study will conclude by discussing the implications of increased creative confidence on improving innovations in New Product Development.

2 ROLE OF CREATIVE CONFIDENCE IN IDEA GENERATION

According to Bono (2007), the word 'create' means to set up something with value that did not exist before, by which creativity can be defined as bringing into existence something that has value. Many authors (Bono, Chandle, Sharp) state that creativity can be taught and it is something we are born with but we lose as we get older if we do not exercise it, as Anderson (2006) claims it is the non-creative behaviour the one that is learned.

Confidence is defined by the Oxford Dictionary as the feeling or belief that one can have faith in or rely on someone or something. Belief and relying are important within idea generation and management as it is a collaborative process in which participants must trust in others and be open to share ideas, thoughts and opinions. It is a core skill in idea generation processes, as it is needed to express people's ideas. The relation with this project is to understand how people can have not just confidence but a creative one on the innovation progression within a company and how it can be built by a solid framework and tools to support it.

In current literature we have found there are three approaches to creative confidence: (i) physiological, (ii) social and (iii) work environment influenced. Psychologically creative confidence has been defined as the ability to come up with breakthrough ideas, combined with the courage to act (Kelly and Kelly, 2012). The approach of Kelly has been to look at it from a psychological point of view, focusing on understanding the fears and behaviours that block creative confidence. They offer examples from the work of Bandura (1977), a Stanford professor and well-known psychologist, relating to his experiments about getting over a fear. From their research they identified four key types of fears that constrain creative confidence. The first one is the fear of the messy unknown, which means the apprehension to get into an unfamiliar field. The second relates to the fear of being judged, by which people usually gets stuck to safe ideas to avoid rejection. The third connects to the fear of the first step and the last one about fear of losing control by leaving their comfort area. However, this approach does not offer a clear example of how to restore and enhance people's creative confidence with specific tools and methodologies.

Socially, creative confidence is linked to our childhood. Common approaches are based on reminding people how creative they were during their childhood (Chandler, 2012) and restoring their confidence to improve the idea generation process. Land (1992) states the "non creative behavior is learned". This assertion is based on his comparative study where he tested 1600 children's creativity when they were 5, 10 and 15 years old; and the compared them with 280,000 adults. The genius level creativity results were respectively 98% at the age of 5 years old against 2% for the adults.

A third approach to Creative Confidence relates to self-efficacy and how it is influenced by individual factors, supervision and work environment (Chong and Ma, 2010). Their work focuses on the concept of creative self-efficacy and determining that individual (such as ethnicity, polychronicity, managerial experience) and organizational (supervisor support, risk taking, collegiality) factors have an impact on idea generation.

3 CURRENT IDEA MANAGEMENT PROCESSES

Idea generation can be discussed from two different approaches, either from a process or outcome perspective. Nelson (2009) argues that the outcome perspective is usually more prevalent. Other authors have a more focused approach of idea generation in relation to innovation practices, for example, Sutton (2002) claims that the improving standards of innovation techniques are an enhancing idea variance. He also suggests that active imagination is very important for idea generation, seeing the old things in a new way by giving a fresh perspective to every challenge faced, as innovation aims to break with the past and bring into life something new.

Traditional approaches to the ways in which organizations generate ideas are radically changing (Sowrey, 1990). For example, many companies have set up diverse web tools to help them improve their idea generation process, such as *Brain Juicer* used by Nike and Nestlé, which provides fast feedback and is deemed to cost effective, or *Mind Manager*, used by Bayer for brainstorming. Gumble (2003) provides examples of the specific advantages of these new web based approaches, by indicating how web tools can offer the opportunity for both loud and the quiet personalities to simultaneously submit and evaluate ideas, getting rid of what he defines as *the power of the pen*. From the psychological point of view, the main advantage of web tools are that they provide the

opportunity for anonymous contribution by employees to generate, publish, evaluate and select ideas without the worries of feeling biased or constraint by others opinions.

At the early stages of idea generation many business are attempting to integrate information technologies to create a robust base. According to Gordon (2008), technology usage in the early stages of the fuzzy front is helping internal teams to improve their innovators productivity by collaborating and exchanging the information for solutions, analysis, simulation and visualization, in summary, ideation. These approaches are integrated into both online and offline strategies. In fact, some companies are integrating social networks to enhance their new product development from idea generation to idea evaluation (Kijkuit, 2007).

The changing approaches to idea generation are being paralleled in the search for new sources of ideas. According to Alam (2003), companies and managers do not need to obtain ideas from just customers, suppliers, universities and even competitors but from what he defines as *unutilized sources*.

Over the last few years companies have gone from closed innovation to open innovation. For example, companies such as IDEO and P&G have opted for open innovation, which means open platforms where people from outside of the organization can provide knowledge, ideas and input to a series of exposed projects. Chesbrough, (2003) suggests there are two sources by which organizations can get ideas from: (i) innovation investors (in house Research & Development department) and (ii) benefactors (companies funding early stages of innovation projects from outside of the company). However, idea generation by in house employees is still very common. To enhance the in-house process, Wood (2003) advocates the use of idea supervisors (facilitators) in idea generation workshops so that participants can feel encouraged and supported. The use of idea supervisors helps make sure participants feel part of the idea development process providing techniques and encouragement not to be afraid of failure.

Björk J. and Magnusson M. (2009) have examined the use of social networks as a source of ideas. Based on the analysis of a database from a sample company, with an active idea management process, they found a strong relationship between network connectivity and the quality of the ideas generated. They also identified that ideas created among people with a wide and supported network resulted in an increased number of high-quality ideas. Social networks have are also being used for idea evaluation (Kijkuit, 2007). Kijkuit (2007) suggests social integration does not affect in a negatively to the quality of the idea evaluation.

Currently there appears to be no universally agreed set criteria for idea evaluation. However, there are several examples for go/no-go decisions. For example, Anon (2008) claims it is beneficial to use none specialized people for voting ideas, as they will not worry about other people's opinions. From a psychological point of view, using web tools seems to block behavioural embarrassment when making a public contribution to judge ideas Gumble (2003).

Dean et al (2006) state there are two metrics for idea generation evaluation: (i) novelty, defined as rarity or unusualness, and (ii) quality, relating to how an idea addresses a problem at hand, offers an effective solution and is feasible. Nelson and Yen (2009) suggest combining in one single metric variety and novelty as they are very related. They state that variety quantifies the usefulness of the exploration of the novelty.

The final stage of idea management focuses on idea selection, which is usually based on idea quality, its feasibility and its success to solve the problem. To enhance this stage, Girotra et al (2010) examined two kinds of team structures, one in which people work together all the time and one in which each person works independently and then they all work together. They established that the second group performed much better, being able to generate more quality ideas and discern among them to select the best ones, highlighting how counterproductive a brainstorming session can be for idea generation as the capacity to differentiate the good ideas from the bad ideas decreases versus the iterative process in which people generates them independently and then share them and work on them together afterwards.

From a large company point of view, ideas are usually selected by low senior managers, and often they are not the ones the senior managers would have selected, which represents a complex issue for new product development and innovation teams Reitzig (2011). To enhance this process, Reitzig has developed an innovation funnel so there is a consistent management control for idea quantity and

quality proposed by employees within the company. What this paper demonstrates is that companies should invest as much in idea selection as they do for idea generation.

4 THE IMPACT OF CREATIVE CONFIDENCE ON NPD TEAMS

There appears to be a paradox between creativity and productivity, which refers to how things are produced in relation with time, money and people needed to make it real. Productivity is usually referred in some way to efficiency although it may vary depending on the discipline involved.

In a work environment productivity is affected by very diverse factors, Tahira et al (2007) claims that job insecurity increases productivity levels among the employees but creativity, considered as problem-solving skill, decreases drastically. Moreover, creativity and flexibility decreases as well with downsizing when employees feel threatened to be laid-off). On the other hand, Steven et al (2008) state the incentives for high levels of creativity can help reduce mediocre ideas during idea generation process, however, it does not increase breakthrough ideas.

From the literature reviewed, it has highlighted the paradox between creativity & productivity. For example Chang and Birkett (2004) explore this issue in terms of different work environments. For example, an organization is not very focused on innovation, productivity will be considered more important than creativity whilst in an organization where there is a need for innovation the importance will lay on creativity over productivity. It should be desirable to find a way to balance the two of them, by training the managers or by implementing an innovation management culture within the company that addresses both issues.

The creative performance of employees seems to be affected by several factors according to the literature reviewed. According to Liu et al (2012) the creative performance of employees can be jeopardized by an abusive supervision by their managers, which is easily constrained by performance promotion motives. On the other hand, Stobbeleir et al (2011) argue that in a creative work environment, employees' performance can be enhanced by an active feedback, sought from a wide variety of sources. In this context, employees establish a "positive" behavioral strategy that impacts on their self-regulatory behaviours within their creative processes that helps them to achieve their outcomes.

Baer (2012) defines creative performance as the implementation of ideas to achieve business outcomes. The production of ideas is more common than their conversion into innovations (Levitt, 1963). However, this process can be enhanced through several measures by improving: creativity, implementation instrumentality (money and idea implementation related), networking abilities (build up a network to get things done), the way strong ties established (it is easier to get ideas implemented if your colleagues are close to you), implementation and control variables (education, position, division membership and tenure). Baer concludes by stating that creativity and idea implementation are different activities within the innovation process.

Finally, Shalley et al (2009) states that creative performance can be affected by self-reported creativity. In summary, they state how important it is to understand the nature of a the work environment so it is more likely to foster creativity with the work being performed.

According to authors such as Stobbeleir (2011) creative performance in New Product Development teams can be enhanced by creating a culture that encourages the seeking of "active feedback" within the work environment. The adoption of an "active feedback" approach has the potential to aid an individual's creativity through affirmative input from colleagues and managers, that can result in a person being able to enhance their self-efficacy and improve their ability to manage their creative behaviours within the innovation process.

5 DISCUSSION AND CONCLUSION

Creative confidence can be defined as the capacity to come up with creative ideas, supported by the courage to turn it into actual innovations (Kelly and Kelly 2012). The first research question relates to current influencers in idea generation processes and has been addressed by an analysis of the emerging trends within the domain of idea generation such as creative confidence, creative performance and productivity. It suggests that there is a significantly more emphasis placed on improving confidence through the process improvement, compared to building confidence through individual and or team based creative capabilities. A potential imbalance exists. There is a gap

between the tools and approaches used in idea generation and how effective they are in current activities to better understand: (i) how to enhance people's performance through improving their creative capabilities, and (ii) how and why this will help individuals and or teams to generate better quality ideas faster.

This view is supported by the literature reviewed. Until now, idea management research has focused more on the generation, evaluation and analysis of ideas rather than in employee's performance capabilities. Current research implies that tools act as an enhancer of people's creativity, unveiling a gap between theory and practice in idea management in terms of methodologies, tools and practices. Therefore an opportunity exists, to find ways to more effectively turn creative capabilities into creative confidence. The aim of this study was to address two key research questions. They have been answered with a thorough analysis of best practices and a systematic literature review. There exists a need to identify repeatable ways in which to active the transition of ideas into actual innovations, and therefore improving the productivity of organizations.

This paper suggests that creative confidence can be influenced by three factors. Psychologically, fear can block an individuals capacity to generate ideas within a group context. Socially research suggests Land (1992) that we are born creative and that process of getting older effects our creativity. The third factors that impacts on creative confidence is the work environment.

The literature reviewed highlights how idea generation processes can be affected by social and psychological issues. It also demonstrates how new technologies and social media can help to engage larger groups of people due to their ability to facilitate the anonymous participation of employees within the idea generation process(es). The ability to engage employees, who may lack the creative confidence and or the ability to deal with idea management within their work activities is a key benefit of these emerging technologies. This scoping paper has been able to landscape the topic and identify opportunities for further research, based on the observation that studies typically focus on analysis of generalised frameworks that are often discussed independently of people, is that little emphasis in relation idea generation methodologies and tools has focused on understanding the employee's view point and or on creative performance. The purpose of this study has been explore the two research questions, and to identify possible ways to enhance idea generation and innovation processes through building creative confidence in NPD teams, that will be backed up by a conceptual framework containing tools and practices to enhance their creative performance.

This scoping study proves that creative performance can be an enhancer for New Product Development due to an active feedback seeking approach. The support and advice carried out by managers and colleagues will lead to a more independent approach to innovation in the future. Many papers support the use of tools (Howard et al, 2010), such as templates and stimulus as an active and structured idea generation method in which there must be a balance between productivity and creativity, that aligns with this study that aims to generate this kind of tools to enhance employees' performance.

Past studies on idea generation have been addressed from a traditional point of view, based on tools and methodologies, and this paper has attempted to explore, through the two research questions, the problem of how to generate quality ideas that can be converted into actual innovations. In summary, this paper has highlighted how creative confidence is a potential game changer for the idea generation processes, as it is based on the generation of breakthrough ideas and the courage to act and turn them into actual innovations (Kelly and Kelly, 2012).

The next step will be to develop a conceptual framework from the literature and test its impact on multiple idea generation scenarios in BSKyB, in order to determine the implications of increased creative confidence on improving innovations in New Product Development. It will specifically evaluate the skill sets and tools needed to improve idea generation effectiveness (more, faster and better) in NPD teams.

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A NOVEL APPROACH TO COLLABORATIVE PRODUCT DEVELOPMENT IN THE MEDICAL-EQUIPMENT INDUSTRY

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ABSTRACT

In this study, we summarise the requirements for collaborative product development based on our investigation of the differences in the resources and tools that are needed for the various stages of collaborative product development and the needs of system users during these various stages. We proposed a user-oriented approach of collaborative product development for medical equipment and designed a collaborative product development system with the required functionalities to satisfy different areas according to their roles and workflow. The system we developed can drastically simplify the original complex and dispersed process of product development for intelligent medical equipment, thereby allowing the project team to develop new medical-equipment products and promote interactions among the research and development staff, clinical specialists, and the test participants successfully, thereby resulting in a user-oriented collaborative product development process.

Keywords: collaborative product development, medical-equipment industry, workflow management

1 INTRODUCTION

Due to intense competition in the international market, businesses must be cognisant of research, development, and innovation and must also respond rapidly to the demands of the market to survive and thrive in a globally competitive environment. Because technology develops rapidly with each passing day and consumer preferences are diverse and ever-changing, product life cycles are becoming shorter. In the face of such strong competitive pressure, a business must continually develop new products and consider new product development to be a key strategic activity (Thomas 1993). New product development (NPD) is a complex process involving cooperation in many areas, including the following seven steps: idea generation, project planning, concept development, embodiment design, detail design, testing and refinement, and production (Tseng et al. 2008). However, the key to successfully placing a new product in the market lies in whether the features and design of the product meet the expectations of the targeted consumers and the needs of the end users (Patnaik and Becker 1999, Fowler et al. 2000, Bruseberg and McDonagh-Philp 2001, Ernst 2002).

Product innovation has always been an important route to revenue and profit growth, particularly in the life-science and high-technology industries. These industries have the specific characteristics of generating products with a short life cycle, high technical complexity, and a low chance of success. Thus, to remain competitive, the companies that produce these products must invest large sums of money. In this case, both the management costs and the risks involved in the development of new products are beyond the capacity of many companies (Quinn 2000, Bhaskaran and Krishnan 2009), and the construction of a good model for product development has become urgent (Cooper 1990, George et al. 2005). However, product development occurs in many areas, and the needs of the users vary widely (Sherman et al. 2005). Therefore, an investigation of the construction of the new product development process in this study is focused on the intelligent medical-equipment industry as an

example of our methodology. Our aims were to improve clinical testing efficiency in the medical-equipment industry, to construct a system to facilitate the interaction between the manufacturer and the hospital, and to propose an approach for user-oriented collaborative product development to facilitate new product development.

Therefore, the remainder of this paper is divided into three sections. Section 2 proposes the overall framework of the proposed approach. Section 3 addresses the design and validation of the proposed system. In Section 4, conclusions are drawn, and the overall benefits of implementing the system are explained

2 THE PROPOSED APPROACH

Based on the differences in resources and tools among the various stages of collaborative product development and the needs of system users in the various stages, we constructed a user-oriented collaborative product development approach for medical equipment with a further description of the roles of the users and workflow design. Developers of medical equipment must not only consider the issues of marketing, design, and manufacturing but must also have an understanding of the relevant regulatory environment. Therefore, this investigation focused on intelligent medical equipment only; other issues related to product design for implantable medical devices were not examined in this study.

2.1 Role-based Access Control

In a collaborative product development workflow, and based on the goal of the cooperation, specific task workflows are generated among the team members of the project. The roles of each task and executable work in this workflow are defined, and each participating staff member is part of the same set of users in this interdisciplinary flow.

This workflow can be divided into the following two stages: in the first stage, users assume roles; in the second stage, users execute the tasks that are related to their roles. Each stage has corresponding constraints. The primary constraint in the stage in which users are assigned roles is in screening the quantity of the roles that are collected by the users; the constraints in the stage in which users execute tasks in their obtained roles include to judge whether the user has permission to execute the work in this role, to achieve the security principles of role-based access control (such as least privilege), and to distinguish between right and responsibility.

The users in this system are divided into the following five roles: general members, the supervisor of the collaborative workflow, directors of the collaborative workflow, the performance manager for the collaborative workflow, and the system administrator. The system functions correspond to the roles, and access control is also role-based.

2.2 Workflow Design

Workflow is used to attain cooperation among members through the same logical process. Workflow is used to integrate the distributed tasks (activities) into a unified process. The workflow contains considerable information, for example, the tasks (activities), relations between the executors of the collaborative workflow, the reference information on roles and the tasks of the members, and the roles or the tasks of these members. Workflow ensures the provision of appropriate suggestions to the collaborating team members with appropriate resources (Zhen et al. 2009).

3 SYSTEM DESIGN AND VALIDATION

Based on the user-oriented collaborative product development approach described above, a collaborative product development system for intelligent medical equipment was implemented to facilitate long-distance collaborative product design and development of medical equipment with a detailed description of its structure and the implementation approach.

3.1 System Architecture

A collaborative product development system was designed according to the workflow requirements of the product development life cycle for intelligent medical equipment. The related sub-function

modules include a project management system, a document management system, a knowledge-based system, a clinical testing system, and an experiment application system. In addition, a video-conferencing system, e-mail system, newsletter system, forum, and file encryption mechanism are provided to facilitate the collaborative product development of medical equipment.

3.2 System Implementation

The core system and the associated modules of the developed system for intelligent medical equipment are both varied and complex. As an initial step, we implemented a collaborative product development system for intelligent medical equipment using the tree structure in Figure 1.

3.2.1 Project management system

The project management system is divided into the "New Project" and "Project Maintenance and Operation" modules. The "New Project" module is further divided into personal projects, subprojects, and human trial application projects, which are described as follows:

Personal project: This module is designed to assist members in defining the individually owned projects in a general new product development project. The project applicant, who is the supervisor of the collaborative workflow, is usually the project manager and is responsible for entering the basic information for the project, including the project name, and setting up the code for the project.

IRB application project: This module supports the application process for IRB during the validation period in the product development life cycle of intelligent medical equipment.

Subproject: After the personal project and human trial application project are created, the directors of the collaborative workflow can then choose the respective parent project and establish a subproject according to their needs.

The function of the "Project Maintenance and Operation" module is associated with the auxiliary systems and the following related functional modules that are required during the project: a workflow planning module, a video-conferencing system, a project management system, a forum module, a meeting system and a document management system. The users of the maintenance and operation functional modules are the supervisors and the executors of the collaborative workflow for the new project.

3.2.2 Knowledge-based system

Because information is rapidly changing in the intelligent medical-equipment industry, understanding all of the information from diverse sources is extremely time-consuming and difficult. The system administrator updates the new information periodically using the announcement management function in the system maintenance module (e.g., for system information, seminars, education, and training). This function can help members access the latest system information with seminars, education, and training information related to the intelligent medical-equipment industry.

3.2.3 Document management system

Many files are generated during the course of a project, and a portion of expertise depends on the sharing and accumulation of experiences. For this purpose, the tools in this function block provide file accessibility as shared resources for the members of this system, including file sharing, records of completed projects, and external links.

3.2.4 Accessibility

Due to the unique interdisciplinary nature of clinical testing projects for intelligent medical equipment, both the exchange of ideas and mutual consultations are crucial. To address these requirements, this system provides these accessibilities via e-mail, a forum, and a conferencing system, and the results of the projects are presented in a newsletter that is published by the performance manager of the collaborative workflow.

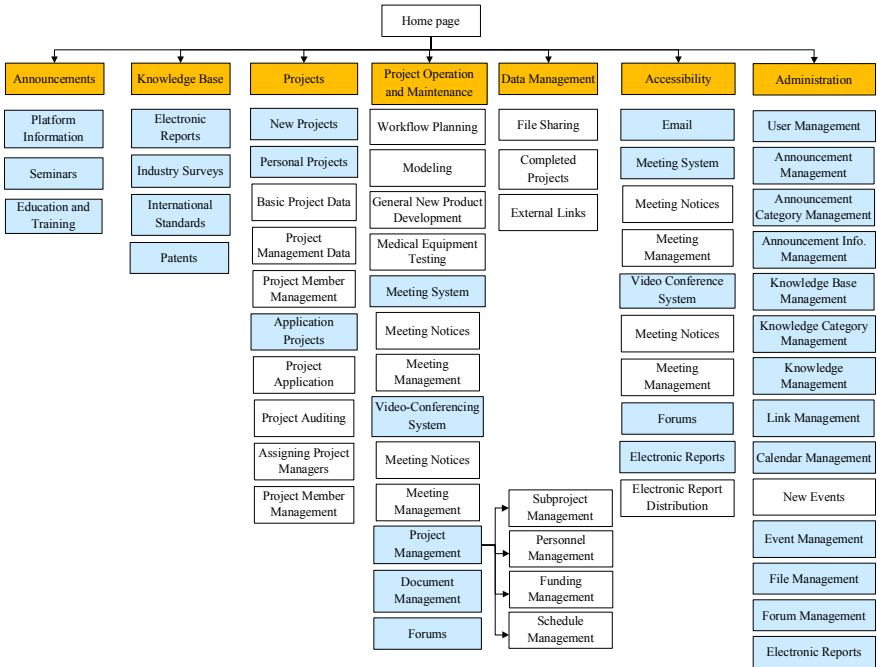


Figure 1: Architecture of the collaborative project management system for intelligent medical equipment.

3.3 System Validation

System authentication was performed with workflow validation for a simulated clinical case using this system. The project tested the acceptance of interactive computer systems in a senior citizen community and can be used as a reference for further development of practical applications for seniors. The scenario begins with the registration of members by the company and the entry of each member's basic information. Next, this information is distributed and verified by the system administrator who allows user login through membership, as shown in Figure 2. The manufacturer subsequently submits an application for testing the project as a member, as shown in Figure 3. Next, the performance manager reviews the collaborative workflow. Following a satisfactory review, the performance manager designates an appropriate staff member to join this clinical validation project as the collaborative workflow supervisor. The supervisor subsequently assigns tasks to each executor of the collaborative workflow, and the application stage for human trials begins. Task assignment involves completing the various parts of the application for IRB. After completing and sending out the forms, the components are entered into the system electronically such that their progress can be quickly retrieved and audited. The clinical trial for the medical equipment is subsequently completed using this system.



Figure 2: Homepage of the membership login system.

Figure 3: The application data fields of the testing project that are filled out by the members.

4 CONCLUSIONS

Based on previously published research studies, we analysed the development process and the resources and tools that are required for medical-equipment product design in which the user needs in each phase of the development process were considered, and a user-oriented collaborative product development approach was proposed for medical equipment. In addition, this study considered further the needs of practical applications in the development of medical equipment by examining realistic cases of medical-equipment development. Based on the functions, specifications, restrictions, and

projects that were applied to the testing phase of the clinical development cycle of medical equipment (classified into user roles and their corresponding tasks and workflows), the user interface and the function modules were designed to meet the requirements of the user roles and their associated tasks, and a user-oriented collaborative product development system was constructed for intelligent medical equipment. The developed system provides the functionality of database creation for professionals in academia, medicine, industry, and other areas that are related to the clinical testing of medical equipment. These users are classified according to their area of clinical and research expertise as a resource for the clinical testing of the medical equipment. With the integration of the relevant units of research and industry, an integrated system of advanced technology with research and development capability can be established for the collaborative product development of intelligent medical equipment.

ACKNOWLEDGEMENTS

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DESIGN & DEVELOPMENT OF A NOVEL HOUSE HOLD COMPRESSING DEVICE FOR A WHEELIE BIN

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ABSTRACT

This project consists of researching, designing, developing, prototyping and testing a device that clamps onto a wheelie bin and easily compresses the waste inside. Once attached, by pulling on the lever, the device will compress the contents inside allowing for disposal of more waste. The design is easily assembled, light and sturdy enough so that any household individual can use it. Prototype testing was performed to identify the required forces necessary to compress a sufficient amount of waste and identifying which materials or types of waste can be compressed. The prototype testing showed that the device is capable of compressing the normal household wastes (compressing plastic bottles, cardboards, tin cartons) up to 45% off the original volume. The paper discusses the design, development and testing of this device to appreciate the proof of the concept as well as discussing it in terms of saving the cost of recycling as well.

Keywords: Recycling, Household Waste, Compressing Device.

1 INTRODUCTION

Since emptying up litter of household wheelie bins takes place mostly after fortnight by UK city councils, therefore in medium to large family households, there wheelie bins start to overflow by the end of first week. Due to living in a neighborhood where the local council does not allows waste within the wheelie bin to overflow or be left beside it as shown in Figure 1. Moreover manual compressing of the litter inside the bin is physically very difficult and hygienically unsafe. Therefore a device capable of compressing the all litter contents inside the bin would be highly beneficial to those who are looking to create further space in the bin as well as making the bin area hygienically safe.



Figure 1: Litter lying outside the bin due to overflow (A common problem)

Currently there is no device on the market that can compress recycling waste at an individual household level. The need for the device was further strengthened from initial questionnaire survey results when various members of general public showed interest in such a device. Achieving the final design was a complex iterative process where earlier concepts were modeled in SolidWorks (Reyes, 2012) CAD software but failed during analysis. This was due to the wheelie bin only being able to withstand a maximum force of only 1900kg (BS 6615. 1996, C.A., 1996). Although this is a large amount of force it was still crucial to focus upon the main priority, keeping the weight and complexity to a minimum. There were iterations where it was believed that the ideal design had been determined, however, when analysis of the mass properties of the device was undertaken it could be seen that the device exceeded the health and safety limit of 25kg's. (BS ISO 11228-1 2003). So achieving a large force to low weight ratio was crucial to achieve as can be seen in the following documented design process.

2 DESIGN PROCESS

2.1 Initial Questionnaire Survey

An initial questionnaire survey involving 28 different houses was performed for a clearer understanding to whether a market for this type of product is available. The ratio of people who do experience overflowing within their wheelie bin and those willing to make a purchase in order to compress their waste is shown in Figure 2.

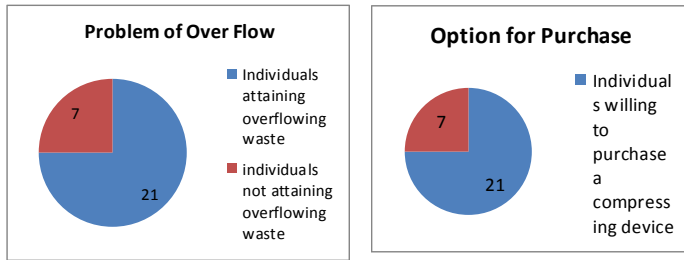


Figure 2: Results of Initial Questionnaire

Clearly all 100% said that they would be willing to purchase a compressing device however it would have to be within the right price range.

2.2 Design Development

Various conceptual designs have been prepared, modelled and tested virtually in CAD/CAE software. Based on the required compression force of 1600 Kg, the first step in the final design was to make sure that the outer periphery of the bin is strong enough to withstand a compressive load application. For this reason a rectangular support plate of 6x578x655 mm was placed on the top surface of bin. Further four 100x50x8 mm box sections of EN8 mild steel (Bolton 2000, Craig 2011) material are inserted under the top edges of bin where the actual clamping device is attached. The actual clamping device consists of a bespoke clamp made up of welding together various hollow cross sections, an off the shelf ratchet to apply compression load and a fabricated pressure plate of 5 mm thickness.

The finite element analysis (Edward 2010) as shown in Figure 4a on the chosen design shows that factor of safety is 203 which means that the bin can withstand 2069kg ($203 \times 100N = 20300/9.81 = 2069kg$) using this given mechanism. Therefore the design is quite safe i.e. it is capable of taking the applied compression force of 1600kg. The displacement is also taken into account with the image shown in figure 4b stating that the largest displacement occurs across the side panels with a value 0.26mm which isn't a massive concern and proves this design is perfectly safe. FEA (Figure 5) was performed on the pressure plate where a maximum force of 1877kg was calculated ($18.42 \times 1000 = 18420N/9.81 = 1877kg$). 277kg above the maximum force of the ratchet, therefore safe for use in this application. The displacement shown is also relatively low with a maximum

displacement of 0.1mm. This indicates that more increased pressure/force capacities beyond the 1877 mark will require thicker plates.

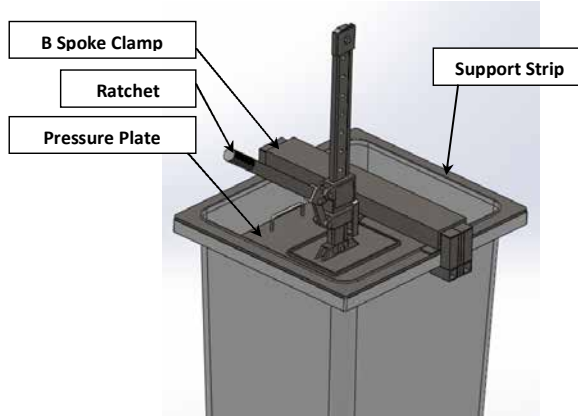


Figure 3: Final Design of the Compression Device

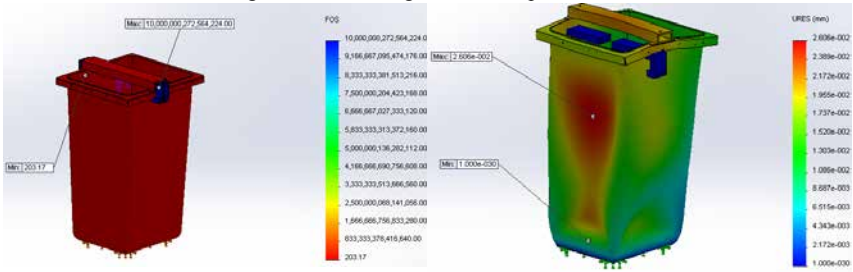


Figure 4: (a) Factor of Safety Analysis in Final Design, (b) Displacement Analysis

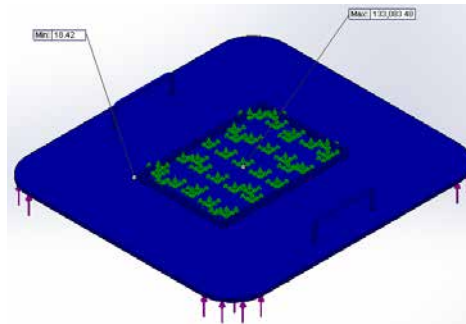


Figure 5: Factor of Safety Analysis of Pressure Plate in Final Design

3 PROTOTYPE TESTING AND EVALUATION

The above design was implemented to develop a full working prototype which was subjected to testing and evaluation. For prototype development, the majority of the joining methods (Beddoes

1999, Groover 2010) implemented were achieved using welding techniques. This was due to analysis conducted on SolidWorks showing that this type of joint would not fail and from advice of different manufacturers that this was the cheapest and lightest solution. All cutting was done using an angle grinder (Maekawa 2000) and again this proved the most practical and beneficial method (Groover 2010). The full working prototype was prepared according to standards (BS 6615, 1996, BS ISO 26303, 2012) and is shown in figure 6. Prototype testing was carried out in two stages:



Figure 6: Full Working Prototype of the Compression Device

3.1 Testing with all Forms of Recycling

The first stage was to be carried out crushing all forms of recycling, for example, glass, cardboard, paper, plastic bottles, cartons, cleaning products, and other various objects. The reason for compressing all types of waste was made due to Bournemouth city council stating that all of the above are classed as recyclable (PD CEN/TS16010 2013). The results are shown below in Figure 7 (a) and 7 (b)

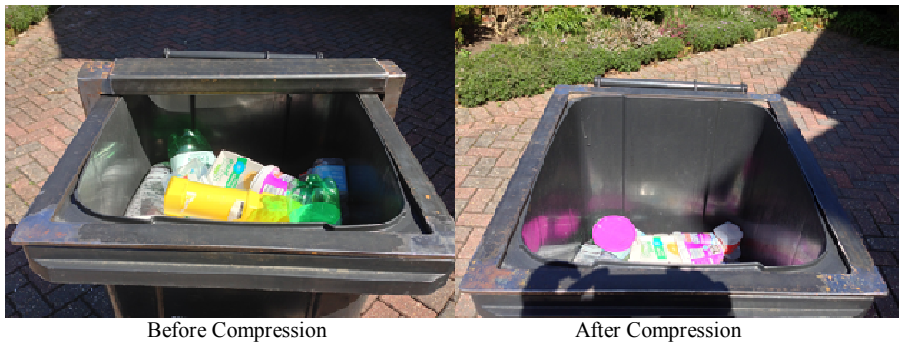


Figure 7: (a) Before Compression (b) After Compression

The results are fairly significant. Measurements for the amount of compression were taken and are as followed:

Before compression: waste = 100mm from top wheelie bin

After compression: waste = 500mm from top of wheelie bin

Compression = 400mm = 40%. These are excellent results since all forms of waste were under compression.

3.2 Test with no glass

Southampton council laws state that no glass is allowed within recycling wheelie bins so the next task required taking all the glass out of the wheelie bin and keeping all other waste materials. The results are shown below in Figure 8



Before Compression

After Compression

Figure 8: No Glass Test (a) Before Compression (b) After Compression

It is clear there is a comparison between both tests as both show excellent results. It is also worth bearing in mind that during test 2 half of the recycled material within the wheelie bin was already compressed due to the previous test. This suggests that the results would have been further improved if all material hadn't already been compressed. The results are shown below.

Before compression: waste = 80mm from edge of the bin.

After compression: waste = 500mm from edge of the bin.

420mm of compression = 42% with room for improvement.

3.3 Post Prototyping Customer Review

The results from the customer review show that the majority of potential customers were happy with the operation and handling of the compressing device. One lady found it a little heavy and difficult to assemble, however the other 9 study subjects (5 men and 4 women) said it was fine. All the men said operating the device was easy and only two women said it was a little hard towards the end. However this can be overcome just by putting more rubbish in and lowering the compressing distance or just using a more powerful ratchet. A cost price for the device of £55~£70 was indicated to be acceptable keeping in view of the achievement of good results. All the members of the public who participated in the test said that the device felt safe to use up to the point of maximum compression. During disassembly two persons struggled to disassemble the device, however, once the correct disassembly sequence was established and understood, everyone found it easy to do so.

4 CONCLUSIONS

From an idea derived from watching people jump into bins to make more space and developing this idea to design and create something that can manage that task in a much safer and improved way has made the whole project worthwhile. The above discussion clearly shows that the first stage testing of the prototype achieved functional aims and objectives of the project. The device also had to be easily assembled and mounted upon a wheelie bin; again this was also achieved well within time. Assembly takes no longer than 2 minutes and compression of the waste takes no longer than 5 minutes.

Disassembling takes 2 minutes as well with a total of 9 minutes to acquire nearly 50% more waste disposal. Each component weighs no more than a couple kilograms with the whole assembly weighing only 14kg which is well below the defined maximum safe lifting load of 25kg (BS ISO 11228-1. 2003). The device is safe and easy to operate with the full system only. The cost of

prototype development was £76 (ratchet cost £28 and device cost £48). After close inspection and advice from different manufacturers it was estimated that if the system was to be mass produced it should cost within the range of £30-£40. Allowing for a mark-up of around 44%, the retail price would be roughly £62.50 (this falls well within the £55 to £70 expected price derived from the questionnaire survey). If recycled metal could be used then these values would be significantly reduced. The market for this type of device exists, according to initial questionnaire survey results.

Further market research with regards to the actual design was carried out with all individuals stating the design was a worthwhile project and some participants even wanted to borrow the prototype to use it at their own homes. Tests also show that no waste protrudes up and out from the sides of the pressure plate as exact dimensions were taken to develop the prototype thereby increasing the safety and reliability of the product.

5 FUTURE WORK

The developed solution proved highly effective and fit for purpose as a compression device. In the next stage of the project, following work can be carried at various stages of the development of the device, so that it can be launched as fully commercial product in the market:

- Identifying further lighter materials in the market with the same or similar strength characteristics, rather than relying only on mild steel.
- Completing further research into ratchets with higher tonnage so that when lower depths are reached compression can be maintained (with a ratchet, as the distance between the base and the lock is increased the tonnage is slightly decreased). This would save having to disassemble, put more waste in and compress again.
- Researching easier assembly methods whereby using lighter materials one component can be assembled upon the wheelie bin rather than piece by piece.
- Identifying different compressing devices for different bins such as general waste wheelie bins and garden waste bins.
- Designing a whole new wheelie bin with a compressing device already attached to it so that the device doesn't have to be disassembled each time it is used. This would save time and would make the device far easier to use. However cost will be affected unless the council would be willing to take interest and invest.

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TACTILE GRAPHICAL DISPLAY FOR THE VISUALLY IMPAIRED INFORMATION TECHNOLOGY APPLICATIONS

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ABSTRACT

This paper presents an interactive tactile graphical display, for the visually impaired information technology access applications. The display consists of a matrix of dots. Each dot is an electro rheological micro actuator. The actuator design and development process is presented in this paper. Prototype size 124x4 dots was manufactured. An advanced software tools and embedded system based on voltage matrix manipulation has been developed, to provide the display near real time control. The experimental tests carried out into the developed prototype showed that each actuator of the matrix was able to provide a vertical movement of 0.7 mm and vertical holding force of 100 to 200 mN. The stroke and dynamic response tests showed the practicability of the developed tactile display, for the visually impaired information technology applications.

Keywords: Visually Impaired IT applications, Tactile Graphical Display, ER- Industrial Applications

1 INTRODUCTION

Electronic refreshable graphical tactile display is one of the most effective interactive tactile interfaces approaches for the visually impaired access to Information Technology (IT). Tactile displays show the information by simulating the sense touch. They are used as reading and IT interactive tools for visually impaired and blind people. The most common patterns available commercially are in one row form and called a text display. In most cases the display is placed under a conventional computer keyboard or laptop keyboard or integrated as part of the keyboard and enables the end user to read the contents of the computer screen by touch in Braille. Each cell has eight dots made of metal or nylon, which are electronically controlled to move up and down, to display a Braille version of characters, numbers, punctuation that appear on the personal computer screen (H. Fisher, R. Trapp, B. Hofman, 1996, P. D. Atherton and K. Uchino, 1998, Kohl, S. Durr, E. Just and D. Pirck, 1998, Fricke and H. Baehring, 1994, Yobas L., Lisy F. J., Schmidt R. N., Huff M. A., 1998). Braille displays designed for use with desktop PCs are around 70 to 80 cells in length. The conventional Commercial actuators used in these applications were electro-mechanical actuator in a form of very tiny solenoid or piezo-ceramic bending element actuator (P. D. Atherton and K. Uchino, 1998). The electro- mechanical actuator using very tiny solenoid has been used to latch a pin, up or down. One of the major problem faced these kind of actuators were prone to stick, due to dust and dirt. The piezoelectric actuator concept is based on using a little piece of ceramic substrate that's shaped to the right dimensions, applying 200 volts and precise operating frequency on it, the dimension of the piezo actuator element changes (P. D. Atherton and K. Uchino, 1998, Kohl, S. Durr, E. Just and D. Pirck, 1998). The main issues with those actuators technology is that they are expensive since the price of a Braille cell of eight dots, is about 35 Euros and the cost of a Braille display of one line of text around 10,000 Euros.

One of the proposed universal approaches to reduce the cost is a force display that has a pointer device, such as a computer mouse and a small tactile display on it. The VirtTouch mouse is based on the idea of, a finger or few fingers are rest on the display and the content is refreshed as the mouse is moved along, to interpret virtual tactile image. The cost of this type of displays is around 5,000 Euros. However the information these devices can transmit, to the skin is limited. This is because

much information is collected by dynamic mechanoreceptors in the skin while fingers explore a surface, because of the slip or tangential forces. This cost barrier show that none of these micro actuators technology is economically good enough, to be implemented in high resolution and large scale displacement tactile graphics displays that are explored with the finger. Therefore, there is still a great attention in new micro actuators technology which could allow a more inventive functioning in terms of operability, manufacturing process, integration, performance and cost (S. Hata, T. Kato, T. Fukushima, A. Shimokobe, 2003, Fricke J., 1993, Taylor P. M., Pollet D. M. Hosseini-Sianaki A., and Varley C. J., 1998, Moy G., Wagner C., Fearing R. S., 2000, Moy G., Singh U., Tan E., and Fearing R. S., 2000).

There are a wide variety of prospective and most of the activities were focused on electrical simulation, which is an old idea but it has not got the desired results yet (Kohl, S. Durr, E. Just and D. Pirck, 1998, Fricke and H. Baehring, 1994, Yobas L., Lisy F. J., Schmidt R. N., Huff M. A., 1998). Here are some examples: Shape memory alloy (SMA) actuators, these are actuators made of wires and its length changes to around 5% when heated by a current of a level of 2A. Most problems to be solved for such technology are small stroke, high power consumption, slow response and need of small mechanical structures. Pneumatic actuators, these are actuators electro-statically actuated. These are bulky ones, unless they use micro actuators, to control the flow, such as, actuators in Micro-Electro-Mechanical Systems (MEMS) technologies (P. D. Atherton and K. Uchino, 1998, Kohl, S. Durr, E. Just and D. Pirck, 1998, Yobas L., Lisy F. J., Schmidt R. N., Huff M. A., 1998).

Pneumatic micro actuators that are based on Electro- Rheological (ER) fluid technology have great attention since the response of the ER-fluid is fast, almost in msec, but the resolution and stroke are poor (Taylor P. M., Pollet D. M. Hosseini-Sianaki A., and Varley C. J., 1998, Block, H. et al, 1989, P M Taylor, et al, 1996, M. Shafik, et al, 2005, M Shafik, 2012). The main phenomenon of the ER-fluid is focused on the physics nature of the fluid and its natural sensation to change from one phase to another when an electric field is applied. The density of such fluid changes as the electric field increase. The ER-fluid is comprises of a colloidal dispersion consisting of insulative base oil and a slightly conductive dielectric solid particles, in the size of 10 to 50 microns. A commonly accepted explanation of the ER-fluid effect is that in the presence of an electric field, the particles became polarised and attract each other accordingly. It is the electrostatic forces between particles that hold the structure together in a solid state. These forces are obviously dependent on the strength of the electric field applied (Kohl, S. Durr, E. Just and D. Pirck, 1998, Block, H. et al, 1989, P M Taylor, et al, 1996, M. Shafik, et al, 2005, M Shafik, 2012). Fricke J., 1996 has developed a display based on these fluids and has showed the possibility of improving the performance. The tactile display developed in this research is presenting a real breakthrough in IT access application and overcome most of the aforementioned technical barriers, at lower cost.

2 STRUCTURE OF THE PROPOSED MICRO-ACTUATOR

There are several key approaches that can be used to form the convexity of a surface, to meet the standard criteria of Braille display IT access applications. These can be classified into two main principles, which are linear movement and rotational movement. The proposed micro actuator structure is based on the linear movement principles. Figure 1 shows the schematic of the proposed micro actuator. The actuator consists of a small cylinder made of ABS material, with dimension of 1.5 mm diameter and 10mm long. The inner surface of the cylinder is coated by nickel. A coaxial conducting rod of 1.02 mm diameter and 10 mm long is fitted vertically in the centre of the cylinder.

The coated surface is used as first electrode and the coaxial conducting rod is used as a second electrode, to form the micro actuation high voltage area. Each micro-actuator was design based on linear vertical movement principles.

3 MICRO ACTUATOR WORKING PRINCIPLES

The principle of operation of the proposed micro actuator is mainly based on the ER-fluid phenomena. When the system is at static start and or at the beginning of a cycle, all pins are down. When the piston is pressurised the fluid underneath, all the pins will be pushed upward to their mechanical limit. Application of an electric field across the high-field area will “solidify” the fluid

between the conductors and isolate the pins from the pressure developed in the main reservoir. Conversely if the piston depressurized, the free pins will be pushed down to their initial state. This means that at the end of each cycle, when the voltage is released and the electric field on the high voltage area is vanished, all the pins will be pushed down to the beginning cycle by atmospheric pressure. The proposed design allows operation using only double of the actuator number of a display of size NxN matrix. N is the number of rows and or columns in the display matrix. This is made it possible by the perpendicular orientation of the two sets of conductors, i.e. horizontal and vertical ones. Two methods can be applied, time multiplexing and voltage multiplexing. Voltage multiplexing is currently preferred and has been adapted as suggested by Fricke J., 1996.

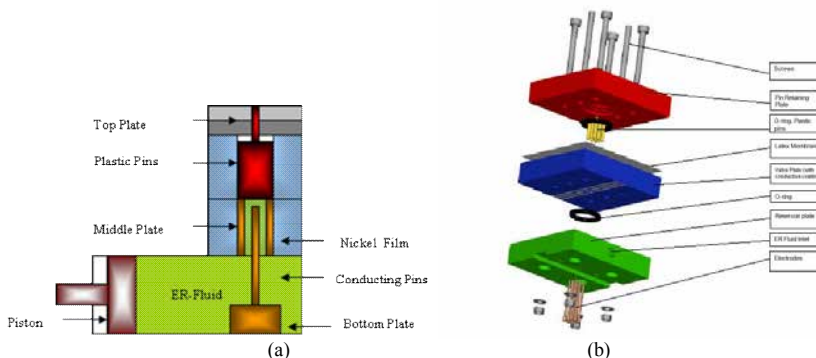


Figure 1: Schematic of (a) proposed micro actuators (b) 3x3 matrix of micro actuator

4 PROTOTYPING, EXPERIMENTS TEST AND VALIDATION

Figure 1 (b) shows an exploded schematic of the 3x3 matrix design structure. Perspex material has been used in manufacturing the first prototype. Perspex is a transparent thermoplastic material which would allow the observation of revolutionize of the fluid characteristics with the existence of the electric field. The prototype is made of three main plates, the top, middle and bottom plate. The top plate was designed to accommodate the plastic pins and to allow vertical movements of 0.7 mm in any position (vertical, horizontal or upside down). This is the standard movement needed for IT Tactile application. The middle plate is to accommodate the ER-fluid and the conduction pins. The thickness of the middle plate was determined considering the ER-fluid characteristics and the vertical holding force needed. The plates were machined in a matrix of holes, each-hole of a size of 1.5 mm diameter. The inner of each hole has been coated with Nickel film of 10 μm thickness using electroless process. The bottom plate was designed as a reservoir for the ER-fluid and has been machined in a matrix of holes of size 1.00 mm. These holes are to hold the conduction pins. The center conduction pins has been made of phosphor-bronze and of a dimension of 1.02 mm diameter.

This gives a distance of 250 μm in the center plate, to be filled with ER-fluid. This was calculated to allow the use of 250 volts drive and to satisfy the standard of domestic invention. The shape of the actuator has been designed on a cylindrical structure, to make sure that a uniform electric field has been created inside the actuator since non-uniform electric field can affect the steady flow of the fluid. The region occupied by fluid which lies between the vertical conducting pins and the coated surface is known as the high-field region. The fluid within the micro actuators is driven by a master piston.

The conducting pins are also co-axial cylindrical electrodes, to ensure that the electric field strength is distributed calculably with radial and axial symmetry in this region. Consequently if the horizontal conductors are grounded and the center conductors are brought to high voltage, the small gap size ensures that the electric field strength is high in this region and this region only. An O-ring of rubber has been used to seal the middle and the bottom plate. Rubber sheeting elastic material was used as a membrane and this was selected to provide three functions for the micro actuator system (Barlow, F. W., 1993, Blow, C. M., and Hepburn, 1982). These functions are: to insulate the ER-

fluid from the other parts of the system. The second one is to deform easily with a minimum amount of pressure and recover its original structure without any fatal destruction into the material micro structure. The last function is to isolate the main parts and stop any fluid leaking. The EPDM rubber sheeting was the optimum options. The Chemical and Physical Properties of EPDM rubber sheeting used were: Tensile stress (TB): 12.8MPa, Elongation at break (EB): 150%, Hardness, shore (HS) = Shore A 78, Volume Resistivity: 10Ωcm, Resistivity: Oil resistance material, Working temperature: 40 °C app, Physical dimensions: 0.050x360 x 360 mm, 0.1x360 x 360 mm.

The necessary test rig has been built. This was composed of a hydraulic drive, DC ER-fluid electronic drive, frequency generator and power MOSFET switching unit. Several tests have been carried to the first developed 3x3 prototype. The first test was air pressure test, this aimed to ensure the legitimacy of the movement principles used on the actuators design. The second one was fluid test and this was aiming to test the ER-fluid practicality. Voltage multiplexing has been used during the test process. This arrangement allows updating the 3x3 matrix prototype one row at a time, i.e. conductors 1 – 3 can be at either 0 or 350V. Individual actuators on row 1 will be controllable by the column drive circuitry. It is then possible to build up a complete tactile graphical display of any large scale using this methodology and would be able to display a complete “image” on the array row by row.

Series of theoretical and experimental analysis to define the performance of the developed micro actuators to be implemented in high resolution tactile graphical display has also been conducted. The main standard criteria of Braille were considered as a first priority. A consideration of expected behaviour of the micro actuators due to the manufacturing tolerances was then conducted followed by a consideration of current consumption against the position of the conducting pins in the core of the micro actuators.

4.1 Standard Criteria of Braille

The vertical holding force for each micro actuator was measured and it was found that each one was able to carry a vertical holding force equal to 200 mN. The practical test showed that the actuators were able to provide 0.7 mm at a pumping pressure of 2.5 Pascal. This was measured at the end of the pumping tube and with an EPDM rubber with a thickness of 50 μm.

4.2 Current and Power Consumption

Current and power consumption tests showed that the developed prototype operates at an acceptable voltage on the range of (± 250 to ± 350 V). This voltage is low enough that the protection of the end-user can be achieved without great difficulty and low cost devices may be used for electronic drive circuitry ($< \pm 400$ V). Current consumption at room temperature has been measured at 1.5 μA per actuator, giving rise to approximately 3W power consumption in normal operation.

4.3 Expected Variation of Actuators

For such micro-actuator technology, studying the manufacturing tolerances consequence on the system performance is an essential process. The manufacturing tolerance in the current system can change the position of the conducting electrode in the center core of the actuator. 1.00 mm holes is used for 1.02 mm diameter electrode pins (tolerance ± 0.01 mm) to ensure a proper interface fit that compensate the drilling tolerance. This is achieved by employing a smaller diameter holes than the pins accurate positioning of the electrode. Variation of the actuators behaviour is therefore only affected by misalignment or slightly bending of the pins. Figure 2 (a) shows the expected behaviour of the micro actuators due to the manufacturing tolerances. Experimental tests were conducted to determine the maximum tolerance allowed, at different voltage, for these circumstances. Expected variations in the actuators behaviour were both focused on power consumption and vertical holding force. The test was carried out using a single 1.00 mm diameter conducting pin inside a 1.5mm cylindrical hole. The conducting pin could be moved from its center position to simulate misalignment. The system was then fitted with a micrometer to accurately measure any offsets from the center pin location. To hold out the desired finger print of 150 mN, the required pressure equals approximately 11 kpa. This is the pressure required for comfortable reading of the pins for the tactile

graphical display application. The force required to depress the pins in order to register feedback should be more than 150 mN, but less than 350 mN force. Figure 2 (b) shows the current consumption versus the position of the conducting pins. It is clearly observable that the current consumption remains fairly constant independent of the position. This means that perfect alignment is not crucial as long as the gap between the conducting pins and the cylindrical tube is bigger than the size of ER-fluid particles which is in the range of 10 to 100 μm .

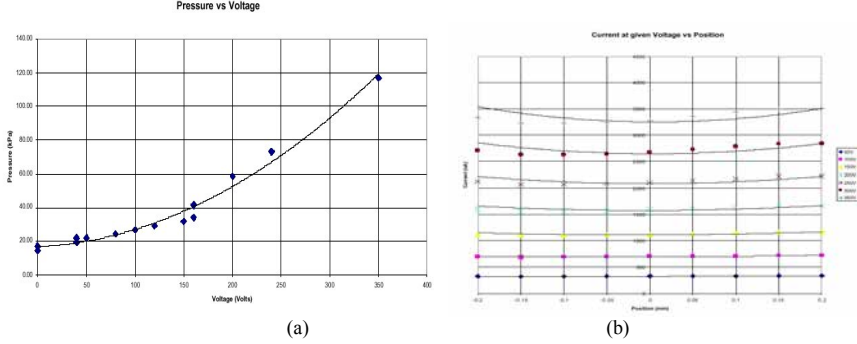


Figure 2: (a) Expected behavior of the actuators due to manufacturing tolerances & (b) Current consumption versus position of the conducting pins

A prototype size 128x4 dots have been manufactured and this is shown in Figure 3 (a). The prototype was equipped with a dedicated control unit. The controller unit consists of a micro controller μC , a hydraulic drive and 270 volt DC power supply card. The μC with the serial interface, 64 Byte RAM, and 128 KByte flash ROM are mounted on a single board. The power supply card and the other electronics are plugged onto this host module. Figure 3 (b) shows an overview of electronic interface & Protocol layout and data flow block.

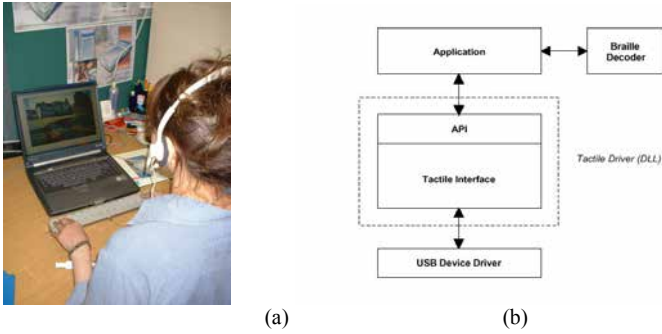


Figure 3: The developed (a) 128x4 interactive interface display prototype & (b) Overview of electronic & Protocol layout and data flow block diagram

The control unit receives the image data via a USB serial interface from an external computer. The image is stored in the RAM of the host module. The control unit continuously reads the data and calculates the pattern to be displayed on the tactile matrix correspondent to the actual image data provided. The software consists of two independent parts running on the μC software and the external computer respectively. The μC software is executed in a time loop of Hz. In this loop the μC read out the data of the image to be displayed and activate the correspondent dots in the tactile matrix. In the next step, it receives new images from the computer and saves them in the local RAM. The software

running in the external computer has the task to generate images to be displayed on the tactile matrix display. Tools have been developed to send parts from the graphics files (*.jpg or *.bmp or html format) to the tactile display. It is also possible to draw directly in the display using a mouse of external computer. For the graphical interface the QT library is used, which allows to run the program under different operating system (such as Windows or Linux).

5 CONCLUSIONS

A tactile graphical display for visually impaired IT access applications has been developed. Prototype size 124x4 on a matrix form, with a separation distance of 2.54 mm, was designed and fabricated. Tests carried out into the developed prototype showed that each micro actuator was able to provide a vertical movement of 0.7 mm and a vertical holding force of 100 to 200 mN. These results satisfy the necessary requirement of Braille IT access applications. The experimental results of the stroke and dynamic response showed the practicability of the developed graphical tactile display, for visually impaired information technology access applications.

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MODULAR LIGHTWEIGHT COMPONENTS FOR PERIPHERAL E-MOBILITY SOLUTIONS

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ABSTRACT

Based on a comprehensive prototype, the researchers at the Otto von Guericke University systematically investigate components and system solutions within a project regarding the interplay of electric vehicles and range extenders. In consideration of the electric vehicle, named Editha, different operating strategies for the use of range extenders in the predominant application field of electric mobility were tested. The principal objectives of the project are to determine appropriate operating strategies for the use of a range extender and operating characteristics for an optimal system configuration of existing or future engine technology in combination with the respective generator technology. Thus, sensible and expedient combinatorics with regard to weight and performance criteria arises. This project aims at gaining an overall understanding of the interplay between automotive and alternative energy generation based on the prototype and the exemplary design of both power trains.

Keywords: e-mobility, range extender, operating strategies.

1 INTRODUCTION

Reviewing the current state of research and the areas of missing knowledge, the project aims at designing a lightweight range extender for electric automotive operation. This is against the backdrop of ever increasing numbers of electric vehicles commercially available. Accordingly, the resolution of previously limited range gains currency regarding the satisfaction of customer demand in terms of the range of these vehicles. Thus, range extenders represent a corresponding solution by removing one of the major hurdles in terms of market and customer acceptance in the field of electric-mobility applications. In this context, a comprehensive market research was conducted to show what applications in the field of electric mobility come into consideration as regards building up a range extender.

The basis for further research is the project Editha (Wagenhaus et al. 2012). Due to its minor curb weight and its specific construction, a Smart was chosen as starting product for the e-conversion. In consequence of the redesign, the previous power train is dispensable. The research vehicle is a battery electric vehicle using an individual DC motor with a fixed gear ratio for each wheel of the rear axle. At this, each electric motor is located in the immediate vicinity of the rear wheel and can be individually controlled by its own motor controller as well. Thus, the Editha project points out a transition from vehicles with central engine to hub wheel electric engines. As a complementary system to the existing electric vehicle, industrially manufactured components, both immediately available parts and at a prototype stage, were evaluated as appropriate for range extenders (Section 2.2).

Range extenders provide the opportunity to combine the advantages of both an internal combustion engine and an electric power train (Section 2.1). Thus, the issues of battery technology

can be circumvented (Fischer 2009). Consequently, a range extender represents a worthwhile type of propulsion technology as a transition from the internal combustion engine to the electric power train. The combination with electric drives enables fulfilling legal regulations in terms of pollutant emissions as well as realising a drive train at minimum costs (Münkel et al. 2011).

A comprehensive review of potential components for designing a range extender systematically offers several configurations (Münkel et al. 2011). The focus of the investigations is a serial electric drive with respect to the use of a range extender as well as its evaluation in operation (Kampker et al. 2012). This assessment is addressed in the context of two alternatives, on the one hand considering the possibility of replacing a portion of the electric battery through the integration of a range extender in a vehicle. Alternatively, a modular range extender represents a technology testing platform in terms of a trailer-range extender. Taking into account the research carried out and the test vehicle Editha, this investigation is used to create a flexible solution for a technical implementation of a range extender in or at the existing vehicle.

2 DESIGN OF THE RANGE EXTENDER

2.1 Operating Strategies for Range Extenders

In this section the requirements and operation strategies are specified. In parallel hybrid drives, the internal combustion engine transmits the operating power via clutch and gear box to the wheels directly. An additional electric drive is integrated in the power train. Accordingly, this offers the possibility to combine the power distribution between the combustion engine and the electric drive (Münkel et al. 2011). Apart from that, a serial hybrid drive in terms of a range extender enables an exclusively propulsion and recuperation of a vehicle by electric drive motors. An additional combustion engine (range extender) only actuates a generator directly feeding the electric battery (Kampker et al. 2012, Tschöke 2012, Münkel et al. 2011). Thus, a range extender represents an additional energy source to extend the electric range out of the traction battery. Accordingly, it generates electric energy on demand in order to actuate the electric drive motors or charge the battery (Tschöke 2012, Kampker et al. 2012).

Parallel hybrid drives imply more weight of the entire drive system due to the permanent redundancy of power trains. Thus, the proposed concept contains a serial range extender that is designed as trailer. Furthermore, it is assumed that the range extender operates in fixed operating points and feeds maximum electric power into the electric vehicle. Furthermore, the range extender, more precisely the loop of combustion engine and generator, operates separately.

Moreover, the following aspects have to be considered in terms of a trailer-range extender:

1. Manual switch in the vehicle for ON and OFF (master switch)
2. Overload protection as regards traction battery (battery shutdown, master switch OFF)
3. Either charging on range extender or mains (locking of range extender during mains connection)
4. Charging even in stand-by of the vehicle (car parks and is closed, range extender charges – particularly concerns 2)
5. Implementing petrol meter as regards range extender in cockpit display
6. Display in the vehicle if range extender operates
7. Warning display that range extender does not work but manual switch is ON (range extender not operating due to fault)
8. Defined discharge status of the traction battery to start range extender (no start if battery has full charge)

Several critical states have to be considered additionally. With respect to a recuperation of both drive motors and simultaneously charging via range extender, an overload of the traction has to be prevented. Hence, a range extender necessitates a specific operation point offering reduced electric power to the battery. A range extender should enable a continuous feeding of the battery during normal operation and, thus, significantly extend the maximal range of the electric vehicle.

Apart from a reliable and stable operation of a range extender, several additional requirements pertain in this context (Larminie and Lowry 2003). The main requirements of an combustion engine

used as range extender focus on minimum fuel consumption, compact design and inconspicuousness in terms of vibrations and noise (Münkel et al. 2011). The combustion engine has to be as fuel-efficient as possible in order to increase the operating distance of the range extender significantly. Moreover, legal and technical constraints regarding maximum weight and size of a trailer-range extender apply. In addition, the range extender should be environmentally compatible in terms of exhaust gases to confirm the sustainable claim of the Editha project. Thus, a petrol engine is preferred as opposed to a diesel engine (Helmers and Marx 2012).

2.2 Design of crucial Parameters

The requirements of an internal combustion engine as a range extender differ significantly from a combustion engine used in a parallel hybrid drive. The required power is in the range of 15 to 30 kW and, thus, considerably low (Münkel et al. 2011). Furthermore, the transient behaviour of the combustion engine is irrelevant due to the fact that the engine actuates the generator in a steady-state operating point. Hence, the operating range of the combustion engine is confined to charge the battery in an appropriate operating point (Fischer 2009).

Based on preliminary considerations of operating strategies, an appropriate set-up of the range extender occurs. Due to a potential range extender directly feeding Editha, specific requirements in terms of merging two different power trains arise. In this context, the precise energy and power demand of Editha has to be estimated. Moreover, a simplification of design is required. Accordingly, several components installed in Editha are also used for the range extender's design due to reasons of standardisation. This concerns both the planetary gear and the controllers as well as the drive motor that can be used as generator as well. Figure 1 illustrates the chosen configuration and the efficiency factors of all components in per cent. In consideration of the efficiency of Editha's power train (Wagenhaus et al. 2012), an appropriate connection of the range extender is necessary. Therefore, an electric link from the range extender between controller and drive motor is proposed. However, a direct feed-in of the battery implies a decreased efficiency due to an additional energy transformation.

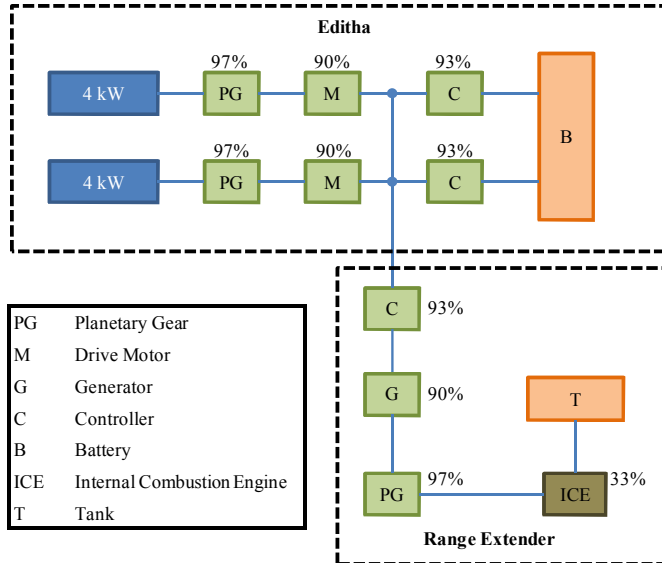


Figure 1: Interplay of Editha and Range Extender.

With respect to the mechanical energy output of Editha needed for an average speed of 80 km/h, an electric power of twice 5 kW has to be offered by a potential range extender. Due to further energy

losses during operation, a continuous driving operation of Editha necessitates an electric power of 11 kW provided by generator, thus a mechanical power of 13 kW provided by internal combustion engine. In addition, the legal towing capacity of Editha is confined. As a result, the maximal weight of a trailer-range extender is limited to 150 kg. Consecutively, an appropriate combustion engine was chosen with regard to both performance and weight criteria. The selected twin engine offers 45 kW mechanical power. In consideration of the weight of 35 kg and consuming 5,2 l petrol, this compact combustion engine meets all requirements (Section 2.1).

3 DETECTION OF THE ENGINE MAP

3.1 Engine Test Bench

In consideration of the design and set-up of operating strategies of range extenders, the knowledge of the specific power generation and fuel consumption of the internal combustion engine need to be addressed. Thus, characterisation of the operational performance and development of the characteristic engine map in terms of consumption necessitate a measurement of the range extender internal combustion engine on an engine test bench.

The engine operating point is defined by its speed-torque characteristic. The entirety of all potential operating points generates the engine map in a two-dimensional representation. Within this characteristic engine map the scope of operation of an internal combustion engine is confined by the full-load curve as well as the minimum and maximum speed (van Basshuysen and Schäfer 2012). An engine map can consist of the specification of discrete values in individual points. In the presence of a large number of individual values over the entire operating range, lines of equal characteristics can be drawn by interpolation. Lines of constant power result in hyperbolas. Common engine maps pertain the specific fuel consumption. Lines of equal specific fuel consumption represent isolines. For each possible combination of speed and torque, the resulting specific fuel consumption can be read from the engine map. Usually, several operating points are possible with different fuel consumption for a certain required engine power (van Basshuysen and Schäfer 2012). Thus, the target is to operate an engine in ranges with the lowest specific fuel consumption.

An engine test bench for determining the properties of an internal combustion engine consists essentially of a electric dynamometer loading the combustion engine and a sampler measuring the supplied amount of fuel. For the determination of the operating performance of an internal combustion engine, it is connected by a rigid coupling to an electric dynamometer. The fuel supply is carried out directly by use of the sampler. Moreover, this enables the measurement of absolute fuel consumption regarding a specific load case of the internal combustion engine at a defined time interval.

3.2 Detection and Analysis of the operational Properties

Operating properties of the internal combustion engine were measured and developments of the characteristic engine map as regards to: consumption, parameters of the speed, torque and absolute fuel consumption were an integral part of the dynamometer tests. In a first step, the coarse measurement of the internal combustion engine was conducted. Accordingly, the parameters to be varied, here values of speed and torque, were divided in different measuring points within a predefined scheme over the entire operating range of the internal combustion engine. In this context, the scheme of measuring points defined an incremental variation of the torque with a fixed speed. Starting at the lowest possible speed of the internal combustion engine the torque is raised gradually up to its maximum. Subsequently, an increase in speed to the next higher level to be examined is realised in accordance with a settling time of the test structure. Furthermore, for each of the individual measuring points a detection of absolute fuel consumption occurred using the sampler. The successive raising of torque within a fixed speed avoids an influence on individual measuring points in terms of an incurred system status caused by the thermal impact of previous measurements. In consideration of the defined thermal ramp-up during conducting the series of measurements, this procedure ensures a reproducibility of the measurements. Regarding the intended steady-state operational behaviour of the engine as a range extender, a thermal ramp-up is essential to represent the future system behaviour.

As a result of the realised measurements shown in Figure 3, a steady-state operation at a speed of 1500 rpm is deduced for an efficient representation of a partial load of 5 kW (red cross on the left). Considering an efficient transformation of fuel used in mechanical energy output, implementing a full-load operation of 10 kW necessitates a speed range from 2200 to 2300 rpm (Figure 3, right).

3.3 Universal Use of Range Extenders

Apart from the utilisation of range extenders in the field of electric mobility, these systems can be used as stand-by generators. With respect to this alternative usage, the survey of the range extender technology gains additional currency. Accordingly, efficient and environmentally compatible combustion engines come in the focus of prospectively scientific research. Against this background, the decentralisation in terms of energy generation is enhanced. In this context, battery electric vehicles act as flexible energy storages balancing the discontinuous feed-in of renewable energy (wind, solar, biogas, etc.).

4 CONCLUSION

In summary, an exemplary solution by means of existing technology and partially modified combustion generator technology represents an initial solution to illustrate the functioning of the merging of two power trains. Hereby, the researchers combined modern and alternative power trains from the traditional internal combustion engine with highly innovative generators and control systems. Against the background of the resulting prototype, statements on evolution and development of new components can be made. Furthermore, the usefulness of relevant components is derived. Editha represents a testing platform that additionally offers an available space (the former engine) for a potential integration of a range extender as unique characteristic.

Characterising the driving cycles and conditions for the determination of appropriate operating points, it can already be noted that fundamental solutions for the combination of combustion technologies for extended range are possible. From a scientific point of view, particularly in the integration of miniaturised combustion technology into the existing vehicle design the question of a use-optimised basic design arises. In addition, the weight problem exists as well as the interplay of power train and energy source with respect to control technology. Thus, the range extender is systematically interpreted as universal benefit for the potential user. The overall scientific benefit thus obtains from the systematisation of combinatorics of different energy sources for generating electric mobility and the related alternative uses.

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CHALLENGES IN THE INDUSTRIALIZATION PROCESS OF LOW-VOLUME PRODUCTION SYSTEMS

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ABSTRACT

A critical part of new product development projects is the industrialization process of new products which affects both time and the cost. The industrialization of new products or variants in low-volume production systems has some specific challenges which are caused by characteristics of low-volume products and production systems. Therefore, an exploratory case study is made within two Swedish manufacturing companies to understand these challenges and compare the industrialization process in high and low volume production systems. The results of the multiple case studies indicate four challenges including knowledge transfer from the projects into production, development of the work instructions, the need for a higher level of training of the operators and production system design and the obligatory tailoring of the new products to the existing production systems.

Keywords: Low-volume high-variety production, production system development, industrialization.

1 INTRODUCTION

Several factors such as globalization, faster evolvement of new technologies and shorter product life cycles force the manufacturing companies to introduce products more frequently to stay competitive in the global market (Bellgran and Säfsen 2010, Chryssolouris 2006). Introducing new products to the market and reaching the intended production volume in time allows the companies to avoid crucial consequences such as lost customers and revenue and early outdating of the products (Hendricks and Singhal 2008).

A critical part of new product development projects which affect the time to volume and product quality is the industrialization process. It is defined as the transition from product design to production and incorporate the activities which make the product producible and prepare it for production (Bellgran and Säfsen 2010, Johansen 2005). These activities are related to both product and production system development including adaptation and verification of them (Berglund, Harlin and Gullander 2012). An efficient industrialization process can lead to a shorter time to volume, a more functional and cost effective production system and higher quality of the product (Almgren 1999, Fjällström 2007, Säfsen and Aresu 2002). In this regard identifying and handling the challenges of the industrialization process is critical to retain competitiveness in the manufacturing industry.

In addition, companies with low-volume production face specific challenges during the industrialization process of new products. Characteristics like highly customized and relatively expensive products, low volumes and a “full make to order policy with guaranteed delivery dates” imposes extra challenges to these companies (Jina, Bhattacharya and Walton 1997).

Qudrat-Ullah, Seong and Mills (2012) point out some of these challenges such as shorter time for design and engineering, more variety in customer requirements and limited possibilities for major changes in the production system.

Although separate parts of the industrialization process have been studied in different research areas, more research about the industrialization process in low-volume production systems is necessary. Therefore, the purpose of this paper is to identify the challenges of this industrialization process. The purpose is accomplished through multiple case studies.

2 THEORETICAL FRAMEWORK

2.1 Industrialization process

Industrialization, also known as product introduction (Berglund, Harlin and Gullander 2012) or product and production preparation (Almgren 1999), is described by Fjällström (2007) and Berg (2007) as the “last phase of product and production development process” which consists of product and production system development, pre-production and production ramp-up.

Almgren (1999) presents a model for product development process which shows that the industrialization process includes activities related to development of both product and production system. Therefore, collaboration of different organizational functions and individuals in a cross functional project team with high degree of work complexity is necessary to accomplish the process (Berglund, Harlin and Gullander 2012). In this regard, project organization and leadership plays a critical role in an effective industrialization process. Clear definition of goals, responsibilities, resource allocation and developing a mutual understanding between product and production system developers are some examples of affected tasks by project leadership and organization (Bellgran and Säfsten 2010, Vandevelde and Van Dierdonck 2003).

Another challenging factor in the industrialization process is priority, timing and integration of the production system development in the product development project (Aresu 2001, Bellgran and Säfsten 2010, Säfsten and Aresu 2002). Prioritizing production system development after the product development can lead to critical risks like shortage of time and resources, implementation problems, production disturbances, frequent maintenance need and late changes during the early stages of the commercial production (Bellgran and Säfsten 2010). Therefore, more integrated development of the product and production system during the industrialization process is suggested (Aresu 2001, Bellgran and Säfsten 2010, Vandevelde and Van Dierdonck 2003).

Adler and Clark (1991) and Terwiesch and Bohn (2001) point out the role of the industrialization process in the learning process of the operators and improvement of the production process during the production ramp-up. They state that number of produced products during the ramp-up process have a direct relation to the learning and improvement of the production process. The ramp-up process is defined as “the period when the normal production process makes the transition from zero to full volume production” (Terwiesch, Bohn and Chea 2001).

Information management during the industrialization process has also been identified as critical for an efficient industrialization process. More formalized structure (Bruch 2012, Vandevelde and Van Dierdonck 2003, Bruch and Bellgran 2012) and applying the stage gate model (Berglund, Harlin and Gullander 2012, Bruch 2012) to both product and production system development can facilitate the information management in the industrialization process.

2.2 Low-volume production systems

Low-volume production systems have different characteristics and requirements from high-volume production systems which are usually the subject of study in product and production system development researches. Jina, Bhattacharya and Walton (1997) present some of the differences between low and high volume production systems in their work (see table 1.).

Qudrat-Ullah, Seong and Mills (2012) present some of the distinct challenges of industrialization in low-volume production systems such as shorter available time for prototyping and high cost of changes in production systems relative to the production volume. Late changes in design caused by misunderstanding of the customer requirements and non-conformity of the design and manufacturing are also identified as the sources of disturbances in low-volume production systems (Bellgran and

Aresu 2003). Resource bottlenecks caused by sharing resources between several projects are another challenging factor in low-volume production systems.

Table1: Comparison between high and low-volume production systems characteristics (Jina, Bhattacharya and Walton 1997)

Characteristic	High-volume production	Low-volume production
Typical annual volume	From 100,000 to 1,000,000+ units per year	From 20-500 and 5,000- 20,000 units per year
Product variety and complexity	Medium with no bespoke products, specialist products are separated into dedicated plants	Very high, some bespoke products are delivered also. All manufacturing in the same plant
Manufacturing planning system	Stabilized by a degree of make to stock with primarily assemble to order	Low-volume with full make to order
Order winning criteria	Variety, delivery speed, "All in" product features	Variety, bespoke products, "Extra features", delivery speed

To overcome these issues earlier and clearer definition of the customer requirements and clarity of the information flow are required (Qudrat-Ullah, Seong and Mills 2012, Srinivasan, Ebbing and Swearingen 2003). Using a functional engineering organization, designing the product within the abilities of the current production system and more collaboration of design engineers with manufacturing can facilitate the industrialization process in low-volume production systems (Qudrat-Ullah, Seong and Mills 2012). The mentioned differences between high and low-volume production systems and the need to find facilitating factors for challenges require more in-depth studies of the industrialization process in such systems.

3 METHODOLOGY

In this research, an exploratory multiple case study approach was selected due to the goal of this paper (Yin 2009) to identify challenges of the industrialization process in low-volume production systems. The empirical data of this paper is based on three case studies within two Swedish manufacturing companies. The industrialization process in product development projects in a low-volume production system were followed in the first two case studies while the third one was aimed to follow the same process in a high-volume production system. The case studies allowed observing the challenges of the industrialization process during the different stages of product development projects. The multiple case study method also allowed the comparison between industrialization process in low volume and high-volume production systems (Yin 2009).

Data has been gathered by means of active participation in meetings, daily activities of the industrialization process and study of the projects documents. In addition, semi-structured interviews were done with the key individuals who were involved in the projects. The gathered data allowed identifying the challenges which could degrade or hinder the industrialization process.

Case A and B were followed over a period of five months within a leading company in the off-road trucks and mining machinery industry. Five different product groups are produced at the company while each group includes different models with numerous options to meet the legislative and customers' requirements with a low yearly demand. Case C was carried out during an 8-month period at a service provider in the automotive industry, i.e. the company was responsible for the development, industrialization and assembly of the product. The company produces its products in high-volumes with limited variants.

The product development project was selected as the unit of analysis. The data was analysed in three steps. In the first step, data from each case was analysed separately to identify the unique challenges of each case. Secondly, a cross-case analysis was done to compare the identified characteristics between the cases to specify the distinct challenges of the industrialization process. Finally the empirical findings were compared to the identified results of the literature study.

4 EMPIRICAL FINDINGS

4.1 The case studies of industrialization in a low-volume production system

Case A and B are still on-going and they basically followed a same process based on a conventional stage gate model. The projects were led by a cross-functional team consisting of a project leader and sub-project leaders from R&D, prototyping, purchase and aftermarket functions. In addition, an industrialization sub-project leader was responsible for following the production-related aspects of the project. Sub-project leaders were also involved in other projects and their daily work activities. Regular and informal meetings were the main way of information sharing. The industrialization and prototype development sub-project leaders contributed actively from the beginning of the projects to manage the product and production development systems mutual requirements.

In addition to those common characteristics, each case had specific characteristics. Case A was a minor product modification which aims to upgrade one of the product modules of a specific product and the total project timeframe is 14 months. The project did not include any pre-series production and had a shorter industrializations process. Therefore, the project is considered as a small product development project. This research presents the results obtained from the first three phases of the project which are feasibility and concept study, design and prototyping and functional and field test.

Case B was a general modification in a product group which consists of five different products. The total time estimation for the project was 30 months with a longer industrialization process including pre-series production. As a result, it was defined as a large project. The results from the first two phases of the project are presented in this paper.

4.2 The case study of industrialization in a high volume production system: case C

Case C targets for the industrialization were mainly related to cost, volume and quality. Since both the product and the production system was new, the industrialization can be described as complex.

The project followed a stage-gate process and was led by two project managers; one project manager was responsible for the product development and one responsible for the industrialization. The industrialization project team included members from production engineering, quality, and logistics. The project members were supposed to carry out the work activities related to the industrialization in addition to their daily work activities.

To coordinate and control the work between the two project groups and within the industrialization project groups regular project meetings were carried out and an engineering change order was implemented. The engineering change order described a process required to release or to change the product design. Information was mainly shared in regular and informal meetings and by means of documents.

4.3 Cross-case comparison

In addition to the above mentioned characteristics, other specifications of the cases are presented and compared to each other in Table 2.

5 ANALYSIS

The findings of the case studies show that an effective information management, project organization, resource allocation and early involvement of production in the project are critical factors for an effective industrialization process of both low-volume and high-volume productions systems. However, the results indicate some specific challenges in the industrialization process of the low-volume production systems.

The first identified challenge is fewer opportunities for training the operators and knowledge transfer from the projects into operation. This challenge is caused by low-volume highly-customized products and full make-to-order policy which do not allow high number of pre-series production and a gradual production ramp-up as the final stages of the industrialization process. Lack of resources which does not allow involving all the production operators in the industrialization process is another reason of this challenge.

Table 2: comparison of the characteristics of the case studies

Criteria	Low volume		High Volume
Case name	Case A	Case B	Case C
Product characteristics			
Yearly Volume	<20	<30	Up to 250 000
Product complexity	High	High	low
Variety (excluding options)	5 variants	7 Variants	3 variants
Production system characteristics			
Cycle time	96 hours	128 hours	55 sec
Number of stations	6	4	10
Flexibility	Different products are produced at the same production line	Different products are produced at the same production line	The production system produces one product
Automation level	Low, mainly manual	Low, mainly manual	High
Job rotation	No	No	Yes
Level of required skills for operators	High	High	Low
Industrialization process characteristics			
Targets for production system development	Applying the minimum changes to the current production system to maintain its flexibility	Applying the minimum changes to the current production system to maintain its flexibility	New production system designed aiming at optimizing for serial production
Prototype development	1 prototype of the modified module	Few prototypes of the whole product	Many prototypes of the whole product
Competence development	One expert line operator participates in the prototype development	Two expert line operators participate in the prototype development	Future team leader & operators are involved in the work but still work in current production
Pre- series production	No pre-series, new modules are assembled on products in the normal production flow	1 product, it can be increased up to 4 based on the customers' orders	1000 products
Work instruction development	Drafted during the prototyping, finalized during the production	Drafted during the prototyping, finalized during the pre-series	Developed during the prototyping
Production ramp-up	No gradual production ramp-up is possible	No gradual production ramp-up is possible	Gradual production ramp-up

The second challenge is developing and finalizing the work instructions. This challenge is also caused by the limited number of prototypes and the pre-series production and absence of a gradual production ramp-up process. This can lead to disturbances during the commercial production.

The third identified challenge is a need for a higher level of training of the production operators. Longer production cycle times and more complex products comparing to the high-volume ones and mainly manual production system require more skilled operators. High commitment and involvement of production operators in prototype development is a possibility to overcome this challenge.

The last identified challenge is relatively costly and time-consuming development of a new production system for new products considering the low volumes of the products and short time for development. Tailoring the product to the current production capabilities is one way to overcome this challenge which can also reduce the need for new trainings for production operators.

6 CONCLUSION

The case studies in this research provide an insight to the challenges of the industrialization process of low-volume production systems. The presented results show that the low-volume production systems have different characteristics which distinguish their industrialization process from the same process in high-volume production systems. Such differences lead to specific challenges in the industrialization process of low-volume production systems as presented.

Overcoming such challenges require developing tailored solutions. Identification of different aspects of these challenges and developing appropriate solutions for them requires more in-depth studies which will be the subject of the future studies.

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REQUIREMENTS ANALYSIS IN THE IMPLEMENTATION OF INTEGRATED PLM, ERP AND CAD SYSTEMS

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ABSTRACT

Product Lifecycle Management (PLM) system implementation is a major investment when the technology is used in manufacturing companies. This paper provides an analysis of the requirements for the integration of PLM systems with Enterprise Resource Planning (ERP) systems incorporating the design aspects of Computer Aided Design and Manufacturing (CAD/CAM) within the product development process. PLM implementation deals with various existing product data and information generated over years both from CAD and ERP systems. Data integration is very challenging and has important impact on future decisions while creating new processes. The information management plays very important role not only in PLM implementation but also in the way this will be used in future production. Therefore it is very important to analyse how product information is transferred to PLM system. It also need to be investigated that what, when and how the data will flow from and to PLM systems.

Keywords: Product Life Cycle Management (PLM), Computer Aided Design and Manufacturing (CAD/CAM), Enterprise Resource Planning (ERP).

1 INTRODUCTION

Product development is a complex process involving many poorly understood variables, relationships and abstractions. It addresses a wide range of issues, and is carried out by people of a wide range of roles using a wide range of practices, methods and systems working with different environments. Cooper's (2001) survey revealed that "80% of products are defined during the development phase. 80% of product's life is beyond factory gate. 46% of resources devoted to the development and launch of new product's are spent on products that either fail or never make to market". There are many factors in product development for these failures. One area which this paper will discuss is product information traceability and how this information flows between different functions. One of the main issues is the reuse of the existing proven product knowledge to reduce the overall product development cost and time.

Companies normally have been manufacturing products for years, and the data produced from product development, to product release, supporting, and obsolete are stored in different systems. Most information is one way or other related to product(s), and is generated and stored in different systems for different functions. However, there is a lack of connectivity between these systems / functions. In practice there is a major gap for finding information of a particular existing product.

The particular area that this investigation is concerned with is how PLM systems are connected to CAD/CAM systems where the digital or virtual products are created, and to downstream ERP systems which supports the production systems. Vijay Srinivasan (2011) defined that PLM deals with creation, modification, and exchange of the product information throughout a product's life cycle. PLM has a main function which is to manage product configuration. Figure 1 illustrates that PLM is connected to two main systems in the product development process, i.e., CAD/CAM and ERP.



Figure 1: Simple Product Information (Data) Flow

2 IMPORTANCE OF PLM IN PRODCUT DEVELOPMENT

The term Engineering Data Management (EDM) and then Product Data Management (PDM) emerged in late 1980s as engineers recognized that there is a need for tracking the growing volumes of design files and documents generated in engineering design and related processes. PDM allowed to standardize the storing and controls of documents, including Bill of Materials (BoMs), Revision controls so that the history of information is captured, and most importantly the relationships between parts, assemblies and sub-assemblies can be maintained. Then came the term Product Lifecycle Management (PLM). While PDM focuses on managing design and product associated data and information, PLM centers on reengineering product development and manufacturing processes related to the whole product lifecycles. PDM is a design-focused technology that increases efficiency within existing product development processes by improving the management of product design data. PLM, on the other hand, is a strategic, process-centered approach that leverages PDM and other technologies, along with consulting services, in order to manage product lifecycles, remake processes, and increase throughput. As a result, PLM improves productivity across the connected enterprise rather than in a single department or a specific process. PDM can be regarded as a subset of PLM which includes the management of intellectual asset information and their relationships. PDM is an important basic requirement that supports PLM, and you cannot do PLM without PDM. PLM includes asset creation through CAD, engineering analysis, digital manufacturing, documentation, images, and software issues. There is generally no creation of intellectual assets in PDM. There are usually few collaboration capabilities within PDM. However, a strong foundation for PLM starts with a comprehensive and strong PDM solution.

PLM is an integrated, information-driven approach comprised of people, processes, practices, and technologies to all aspects of a product's life cycle, from its design through manufacture, development and maintenance culminating in the product's removal from service and final disposal. By trading product information for wasted time, energy, and material across the entire organization and into the supply chain, PLM drives the next generation of lean thinking. The goal of PLM is to digitally transform the life cycle that companies use to conceive, design, manufacture, service and improve your product offerings. This enables companies to capture all their product information and knowledge, and leverage it in an integrated lifecycle process that improves the efficiency of the whole product lifecycle activities from start to finish. Companies traditionally implemented ERP, Supply Chain Management (SCM) and Customer Relationship Management (CRM), are more related to the operations side of their business. All these systems do not have functionality in managing the whole life cycle of products.

There are many functions / activities that will take place in the entire life cycle of product development. These depend upon the type of product, industry practice and procedures, size of the enterprise and many more factors. Some of the most common functions or activities are shown in Figure 2 along with the type of system these activities are using. PLM systems sit in as very critical systems because they are strongly linked to CAD/CAM and ERP systems. The information (data)

flow between PDM/PLM and CAD/CAM is bi-directional in most cases where as the information between PLM and ERP is one way that is information flow from PLM to ERP in most cases. Some of the functions are shared between two or even three systems as shown. One such system is change management.

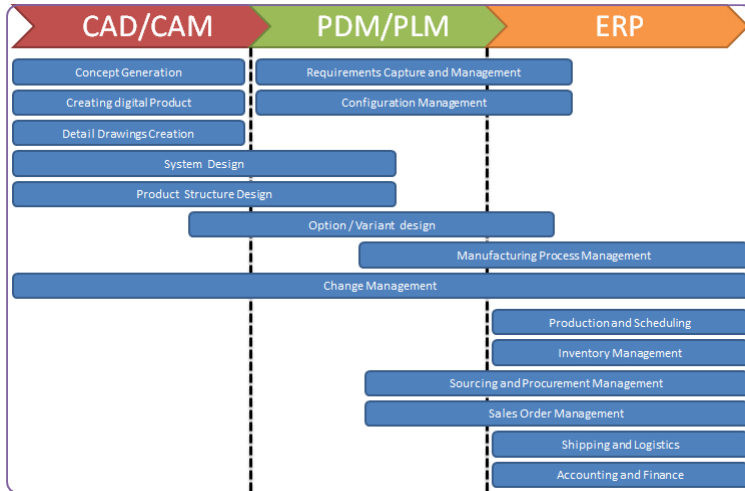


Figure 2: Product Development Activities vs Different Systems [Parametric Technology Corp.]

3 COMMON INDUSTRIAL ISSUES AND REQUIREMENTS IN PRODUCT LIFE CYCLE

An industrial investigation has been carried out in this research, and the results related to common industrial issues are summarised below:

In Engineering main issues and concerns are:

- loss of time and money in reworks;
- slow process in engineering changes;
- differences between product specifications used by engineering production and sales;
- not enough reuse of existing parts; and
- inconsistencies between CAD models and BOM files.

In Global Supply, main issues and concerns are:

- suppliers does not have the information about latest product changes;

In Manufacturing, main concerns are:

- redundant part numbers;
- old version of drawings are provided/used; and
- engineering changes are not timely communicated by designers

In Customer Support, main concerns are :

- technical issues with products in the field;
- inadequate customer service;
- high service costs; and
- product manuals does not have latest information.

In Cross Functions, main issues are information searching which:

- takes lot of time or cannot search the existing product information;
- communication silos – people in different functions not talking to each other;
- data silos –data in one department not being easily available to other departments;
- impossibility to migrate data from a legacy system to a new system;

- many parts, that are either no longer in use or duplicates, are still maintained in the database;
- poor product quality;
- Excel spreadsheets containing a lot of different information about a Product, often conflicting, each other about a product; and
- conflicting lists of the configuration of a product at a customer site.

Common requirements in product development are summarised below:

In the past product development was concentrated on local regions. Products are designed and manufactured locally and then distributed to other regions. Now products are developed and manufactured in many regions of the world which makes company's global operators. The true global companies are emerging to the concept of 'Design Anywhere, Manufacture Anywhere, Sell Anywhere and Service Anywhere (DAMASASA)'. To achieve the Product traceability plays a very important role. How the product is developed by whom and when and where, all these information is very important and gives good traceability about the product. If these information is linked to product life cycles that makes the information accountability as well. The accountability gives information about who and when. This also leads to effective product innovation. In the global companies different functions are performed in different locations for example design teams may be located in several locations in different countries, manufacturing in different locations and sales in different locations. This makes product development even more complex. Good communication system needs to be there for collaborative product development in this new operation context.

4 PRODUCT INFORMATION FLOW ACROSS DIFFERENT FUNCTIONS

Figure 3 illustrates the product data and information flow in industrial case study. This is the backbone for PLM strategies evolved from early product data management (PDM) offerings, usually just focused on managing computer-aided design (CAD) data created and used by workgroups. Companies see the benefits of managing and sharing this information more broadly, extending the use of enterprise PDM solutions to enable collaboration across more functions. Manufacturing companies see the benefits of using this data downstream in manufacturing to better plan and simulate production facilities and processes, using solutions now referred to as "digital manufacturing" to provide those capabilities. CIMdata (2012) estimates from PLM solution providers that the amount of data necessary to produce a car is in the gigabytes, with the engineering work-in-process data, including all of the evolving designs, perhaps an order of magnitude larger, in the one terabyte range.

PLM enables the innovative companies to quickly create right to market products and to leverage part re-use. It focuses on the digital, context-oriented intellectual property (information), functions and business processes. It manages the definition of lifecycle and the relationships between product related information and process.

Invention is the generation of newness or novelty, while innovation is the derivation of value from that novelty. Clearly, innovation is an extension of invention, yet they are distinguished by the fact that the quantity of inventions exceeds that of innovations by several orders of magnitude. Hamel G (2006) stated that "Innovation in whatever form follows a power law: For every truly radical idea that delivers a big dollop of competitive advantage, there will be dozens of other ideas that prove to be less valuable". This may be explained by Patterson M (1995): "Translating a market opportunity into a new product requires perhaps 15% invention. The remaining 85% of the work involves previously learned processes that often are undocumented and undisciplined". Therefore it is very important to manage the information (data) in logical manner so that the existing product information in new product development can be reused which will reduce in time, resources which in turn reduces the overall product cost. This will give confidence in releasing the product to market quickly with RFT (Right First Time).

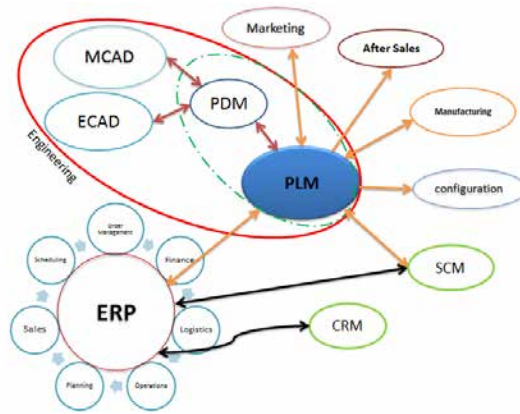


Figure 3: Product Information Flow in the Industrial Case Study

5 PLM IMPLEMENTATION ISSUES

When a company starts thinking to implement PLM it is thinking to change the structure of the Engineering team for sure, and also some other functions which are closely related to Engineering. PLM brings new technology to industry and it will not normally replace existing systems in use.

There are two sides of PLM implementation, the first is how to handle product information after implementation (future planning), and the second one (more important than the first) is how to migrate the existing product data (information) which had been created since company started to the new PLM system. A large number of different types of data is generated during product design, manufacturing, testing and support and service of the product across life cycle. Examples are customer requirements, design specifications, process models, part drawings, assemblies drawings, engineering drawings, analytical models, simulations results, manufacturing tool and fixture designs, test results, quality issue documentation, manufacturing process documents, process plans, engineering Bill of Material (as designed), manufacturing Bill of Material (as built), revision control data, option assembly management, standard product data (as delivered), configurable product data (as ordered), service manuals and user guides. The size of data depends on many factors like size of the company, type of products, number of products and variations, type of systems and many other factors. All these data is very important and is the intellectual property of the company. This data will be in many different formats and depends upon how many types of systems are used in product development. All the data mentioned above is only related to product development. The latest PLM systems can handle many different types of data. Some of the new PLM systems can handle configuration management along with manufacturing system management.

PLM implementation is normally a very big program. Planning is a very important aspect of implementation. PLM is one where product data is initially created and maintained in logical manner. It is very important that this data is populated correctly since it drives all other systems. System integration is very important in total PLM implementation. System integration and related problems are often most difficult and laborious parts of a project.

The improper integration between the systems may lead to the following problems:

- Project delays;
- More resource requirements for project completion;
- Increase in project implementation cost;
- More resource and time in customization; and
- More process to follow after implementation.

Data migration is also very important in PLM implementation. There are some tools which will help migrate data to PLM systems. However this needs to be done very systematically and logically. Very thorough investigation need to be carried out with these data. Data cleaning process need to be

carried out. It may take time to do all these activities, but this would be the roadmap for future product development as well. This will take care of some of the issues mentioned above. Another important issue that need to be taken care of is PLM system integration. As discussed PLM has two way connection to many systems like CAD/CAM, ERP, configuration, manufacturing, marketing, after sales, technical documentation, service engineering and many more systems. Data flows in and out of the systems. All these information need to be maintained in PLM. The three main things that can be achieved are traceability, accountability and securely maintenance of this information (data).

6 CONCLUSIONS

PLM implementation not only creates new processes and methods for future product development, but also deals with existing information (data). It has been identified through investigation carried out in this project that much of the information is generated in different stages of product development.

As highlighted, huge amount of data already exists within a company which plans to implement PLM, hence appropriate tools are required to migrate this data and any future data to be organised in a systematic way which enables to achieve easy traceability, accountability and secure maintenance of this information. Future study within the research will aim to integrate and implement the framework and develop tools to provide solution in allowing the migration of existing information to PLM from different functions; and for future identification of product information to be stored in systematic and logical manner. This will allow the company to resolve most of the common industrial issues and common requirements highlighted in this paper.

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DESIGN OF AN INNOVATION PLATFORM FOR MANUFACTURING SMES

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ABSTRACT

This paper reports on the conception of a collaborative, internet-based innovation platform with semantic capabilities, which implements a new methodology for the adoption of a systematic innovation process in globally-acting networked SMEs. The main objective of the innovation platform is to stimulate the generation of ideas, the selection of good ideas and their ultimate implementation. The platform will support SMEs to manage and implement the complex innovation processes arisen in a networked environment, taking into account their internal and external links, by enabling an open multi-agent focused innovation system, facilitating customer, provider, supplier and employee-focused innovation. The solution is specifically focused on the needs of manufacturing SMEs and will observe product, process and management innovation. The paper presents the key elements of the innovation model and makes references to a novel approach concerning the development of a robust and flexible Central Knowledge Repository for the innovation platform.

Keywords: Innovation Modelling, Innovation Platforms, Knowledge Repositories.

1 INTRODUCTION

Innovation is defined as ‘business not as usual’ by Ziarati (1995). While this ‘Business not as usual’ is primarily a good concept for developing new and unexpected products or services, companies often benefit from improving their products and/or services by applying existing techniques or technologies. Authors are of the view that if a development was not planned as a matter of course, then this is ‘Business not as usual’.

Over the past decade, innovation has gained a unique importance in the world of business. Several studies have been carried out, which reveal that the majority of SMEs are keen to find how innovation can help them improve their products and/or services, or to develop new products or services (Herstatt, and Verworn, 2006; Bullinger, 2008). It is however argued that only a small number of efforts have been made to support SMEs in managing their innovation processes/activities. Little evidence is found that demonstrates work done in business and policy communities to systematically draw on concepts, theories and empirical evidence (Tidd, 2006). However, several pieces of academic research have already been begun in this area (Popova et al, 2007; Ziarati et al 2002). A study by Mangematin, and Baden (2008) shows that around 200 research centres all over the world produce approximately 5000 papers each year, and most of them are inclined towards innovation management. Several publications have emphasised the requirement of setting up an innovation system to accelerate the growth of SMEs (Kogut and Meitu, 2001; Hippel, 2001; Bullinger, 2008).

By realising the importance of innovation, many international companies have already introduced innovation systems in their companies. "My Star Buck Idea" is one of the most popular web based tools, which allows STARBUCKS customers to view existing ideas, comment and vote on ideas and post new ideas related to existing or new products and services.

An analysis of existing innovation systems reveals that there is no such system currently in existence that can be adopted/adapted to meet the special requirements of industrial manufacturing SMEs. Existing systems are either simple, like a "suggestion system", or don't provide the necessary tools and functionalities to fulfil the needs of manufacturing SMEs.

This paper reports on the conception of a collaborative, internet-based innovation platform with semantic capabilities which implements a new methodology for the adoption of a systematic innovation process in globally-acting networked SMEs. The main objective of the innovation platform is to stimulate the generation of ideas, the selection of good ideas and their ultimate implementation. The platform will support SMEs to manage and implement the complex innovation processes arisen in a networked environment, taking into account their internal and external links, by enabling an open multi-agent focused innovation system, facilitating customer, provider, supplier and employee-focused innovation. The solution is specifically focused on the needs of manufacturing SMEs and will observe product, process and management innovation. The paper presents the key elements of the innovation model and makes references to a novel approach concerning the development of a robust and flexible Central Knowledge Repository for the innovation platform.

PROPOSED INNOVATION FRAMEWORK

To overcome the short-comings of the existing models, a comprehensive and flexible, collaborative, internet-based innovation platform system is proposed. This system support SMEs to manage and implement the complex innovation processes arisen in a networked environment. The overall ICT system concept is based on a collaborative platform including functionalities to support the most commonly used Innovation Methodologies in Industry. The current system concept is presented in the Figure 1.

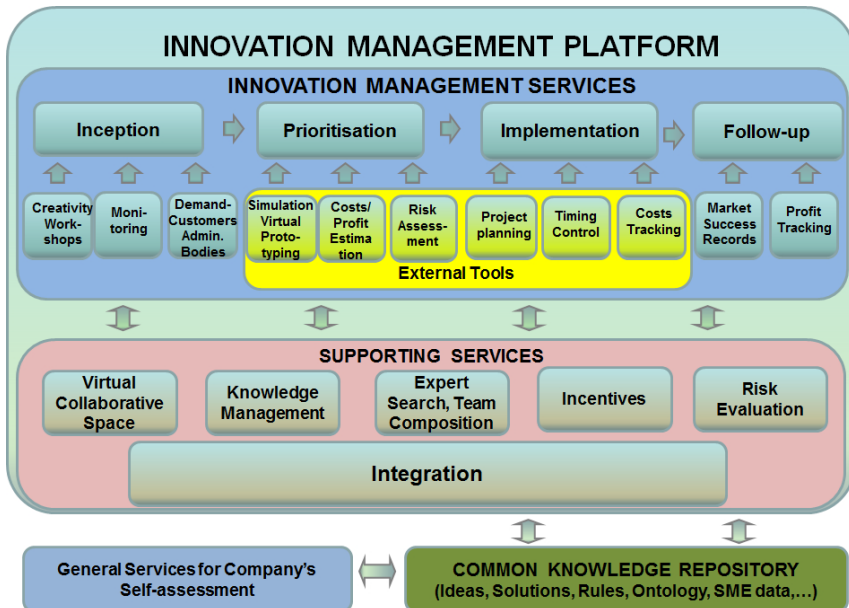


Figure 1: Proposed Innovation Platform

As it is shown in the above figure, the innovation model has been composed of the following components:

1. Innovation Management Services
2. Supporting Services
3. Central Knowledge Repository
4. Learning Organisation

Innovation Management Services

In covering the complete innovation management life cycle, the system consist four innovation services: Inception, Prioritisation, Implementation and Follow up.

Inception Service supports the initial phase of the innovation when the innovative ideas are created and collected . It is similar to the IDEA stage of a traditional Innovation approach. It has to do with the identification of problems, generation of ideas and problem solving, creation of a repository for Innovation Projects, creation of the appropriate environmental conditions to foster Creativity, apply Classical Rule-Based Reasoning (RBR) and Case-Based Reasoning (CBR) approaches, in combination with ontology(s) for similarity matching.

Ideas Prioritisation Service enables analysis of the collected ideas and selection of the most promising ones, based on the predefined criteria. Ideas Prioritisation Services provides ICT support for the 2nd phase of the innovation process – Ideas Prioritisation. The basic concept of prioritisation is the ability to assess and select an idea. The decision support tool involves a combination of classical approaches and new approaches to prioritise ideas on products and processes innovation.

Implementation Service provides support to create the necessary conditions to favour RTD activities, to compose teams, to search financing for the implementation or to schedule manufacturing, and also to support the innovation process management, in terms of monitoring timing, financing, selection of the most appropriate materials/components, and processes.

Follow-up Services support the assessment of the success of the implementation of innovative products/processes, evaluate the effectiveness of the innovative project and keep information about all the previous stages, with all the actions and decisions taken, from the basic idea to the final result.

Supporting Services

To extend the system functionality and usability, a number of supporting services has been added into the framework as shown in Figure 1. All these services can be used according to the application specifications.

Services for the creation of a virtual collaborative space should enable a smooth common multi-tenant usage of the system functionalities by several users from single enterprises, extended enterprises and/or wider communities (open innovation), to work on innovation projects.

The group of general collaborative functionalities/servicess of the system should also comprise knowledge management functionalities, i.e. acquiring relevant knowledge, search knowledge components, tracking and tracing innovation projects, reasoning methods, etc. As a backbone of the Knowledge Management services, an ontology should be implemented. The ontology is built as a modular system, allowing for easy extension, easy handling in distributed environments (like the semantic web), and simple management.

Further collaborative services should be Experts search (external and internal), and Team composition and management from external and internal staff. This allows for composing ad hoc activity groups based on criteria such as Purpose of the team, Availability of team members, Required knowledge areas, and Personal interests.

Services for Risk Assessment should be used as appropriate for ideas prioritisation and innovation implementation. During these two phases, the risks of the innovative product/ process failing either technically or financially are to be carefully evaluated, leading to innovation process adaptation or abandonment.

In order to motivate the employees to participate in the innovation process, services for Incentives Definition should be implemented. These will be based on the number and quality of the innovative ideas and on the preferences of the people who submit the best ideas, as they can help identify the

most appropriate incentives. Some Integration Services should be implemented in order to make the aforementioned services work together.

Common Knowledge Repository

The Repository collects and manages innovation knowledge from all of the members of an extended enterprise for new and existing product and process developments. The Repository, with the support of external innovation tools and services, processes the captured ideas and knowledge; and ultimately supports product, process and/or management innovation.

Common Knowledge Repository for the whole system stores data about Ideas, including also history of all ideas posted anytime in past, Solutions, Rules, Business and Innovation models, SME specific data like plant description, processes description, list of employees with related data, Product and Process related documents, with easy access to product or service improvements, including linkages to customers and suppliers. List of employees with related data can be applied e.g. in the Incentives services as a support to selection of the most appropriate incentives for each of the innovation process participants based on the stored profiles, or within the Team Composition and Expert Search services.

The repository will contain all the knowledge required by the Innovation Platform:

- Knowledge about the innovative SMEs' context, operations and products, i.e. all the information that describes processes and products, needs, ideas and effective innovations. The repository will be modelled with a sustained structure to store the desired information, but which at the same time provides the necessary flexibility needed for its use, needed to interact among different actors, components and services and provide the information missing in manufacturing companies, e.g. interactions and relations between products parts and process steps, ideas and innovations.
- Knowledge about the Innovation Methodology, implemented as a specific ontology, which shall define a common terminology and structuring of data, which is to be maintained at the local repositories. This concept seems suited to the industrial environment, since it represents a compromise between a structured approach – needed to assure an effective sharing of knowledge – and the freedom required to address the individual needs of participants – to not restrict creativity.
- Knowledge about national and international funding opportunities to implement innovative idea(s).
- Link to all the supporting services and external tools to support the innovation activities and processes.

Learning Organisation

The concept of a learning organisation plays a vital role in the innovation process. To be a successful innovation organisation, an enterprise must first and foremost be a learning organisation (Sense, 1990). In order to avoid bad ideas being entered into the system, it is important that users should be aware of the necessary information, such as past experience, principles and policies, related to the idea domain. For example, if the idea is about the design of a product, then the idea proposer should be given the opportunity to learn about past designs and product design practices and principles.

Firstly, it will avoid bad ideas being entered into the system at the initial stage. Secondly, it will boost the knowledge of the people in the organisation.

CONCLUSION

Innovation is a key factor in organisations surviving and gaining a competitive advantage, whilst realising sustainable growth in this hyper-competitive economic playground. The proposed innovation model will help to promote enterprise innovation. It is a stereo structure consisting of four components, which are innovation management services, support services, a Central Knowledge Repository and Learning Organisation. It will support SMEs in managing and implementing the complex innovation processes arisen in a networked environment.

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AN IMPROVED CELL CONTROLLER FOR THE AEROSPACE MANUFACTURING

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ABSTRACT

The aerospace manufacturing industry is unique in that production typically focuses on high variety and quality but low volume. Existing flexible manufacturing cells are limited to certain types of machines, robots and cells which makes it difficult to introduce any changes. In this paper idea of treating machines, robots, any hardware and software as resource has been introduced. It describes the development of the Flexa Cell Coordinator (FCC), a system that is providing a solution to manage cells and their resources in a new flexible manner. It can control, organise and coordinate between cells and resources and is capable of controlling remote cells because of its distributed nature. It also provides connectivity with company systems e.g., Enterprise Resource Planner (ERP). It is extendable and capable of adding multiple cells inside the system. In FCC resources (e.g., tracker) can also be shared between cells. The paper presents its development and results of initial successful testing.

Keywords: Flexible Manufacturing System (FMS), Distributed Network Cell Controller, Cell Controller, SoftPLC, Aerospace Cell Controller, Web Services

1 INTRODUCTION

There is little use of automation in aerospace manufacturing compared with other industry sectors such as automotive, pharmaceutical or white goods. This is because the product volumes tend be small but the product lifecycles may exceed 60 years. High quality parts must be used and all the associated processes must be traceable and verifiable. The variety of parts is also high and this low volume high variety mix means that a large number of conventional automated systems would be required that will have low utilisation rates and therefore be uneconomical.

The Flexible Manufacturing System (FMS) was developed to overcome some of these issues (Greenwood, 1988). FMS utilises the integration of automated component storage, tool delivery and CNC machines with an overall computer control unit to support and monitor the performance of the system (Shivanand, 2006). These FMS installations have been very successful; however in many cases the flexibility has been very low when trying to produce a wide variety of changing components within existing cells. In the case of aero-structure assembly the problem becomes even more complex. This means that multiple processes are likely to be performed using the same processing equipment but in different locations. To enable this, a new approach of cell control and organisation is required. For example a robot may be used for a drilling task in one part of the factory and then used later for applying sealant in a completely different part of the factory.

2 BACKGROUND

A manufacturing robot cell can consist of 20 or more robots along with other machines. They are then controlled by Programmable Logic Controller (PLC). Flexa is the acronym of Flexible Automation Cell. The term flexibility is defined as the system's ability to adopt the change easily. (Fricke, 2000) Flexa is based on the concept of FMS. There are four classes of manufacturing attributes that need to be considered while designing manufacturing system: (i) cost, (ii) quality, (iii) time and (iv) flexibility. FMS is the approach for flexible and cost-effective means of manufacturing. FMS can

consists of two or more computer-managed workstations, material transport system and another computer that controls the transportation operations, tools and other related information. There are a number of components involved in forming FMS like material handling and storage system, programming language and network infrastructure, workstations and human labour. The reason behind using FMS is that businesses want the groups of machines and tools to form a system along with programming and network that can work continuously and with minimal intervention from human labour. (Chrysosouris, 2006)

There are lots of operational tasks of FMS implementation like machine loading, part routing, grouping, tool management, scheduling, etc. Scheduling is an important element (when for about) of FMS operations. Holonic manufacturing scheduling has been used for the scheduling of cells (Gou, et al., 1998) but it doesn't state any communication between the cells and its resources. Moreover although it refers to the automation of cells but any modification in the cells' resources and the processes could take up to a year for planning and implementation.

The computer software applications can be utilized for assistance in FMS. There are several software techniques that are used for FMS and application of service oriented architecture (SOA) in the aerospace industry. This was proposed by the Telematics Department of Hamburg University of Technology (Kazlauskaitė, et al., 2005). Their methodology proposed the collaboration between various enterprise systems in aerospace industry. They used web services interfaces for the integration and communication between existing systems i.e., ERP (Enterprise Resource Planner). The study shows how to make the system flexible by using the SOA approach. They proposed a set of processes along with verification for the implementation of SOA in aerospace industry applications. Their approach gave the idea of implementing SOA for an aero-structure assembly FMS. However their concept does not give any detail how it can interface with the cell and its resources.

RAPOLAC (Rapid Production of Large Aerospace Components) is another example of an automated cell (Gault, 2010) referring to automation of a cell and the resources using the feedback data from a laser tracker. It is also talking about the automation of a single cell and not multiple cells. It does not detail the underlying architecture for the automation. The Automated Assembly of Wing Panel for A340-600 has the similar footprints. (Holden, et al., 2007)

The problem with the current automated cells is that they are not fully automated. There is still a need for manual intervention such as loading programs on controllers, loading programs on PLC, changing programs on PLC etc. A little advancement towards minimising the human intervention is the implementation of SOA. The work for the aerospace industry using SOA was analysed (Kazlauskaitė, et al., 2005) it is giving idea for coordinating between the aerospace industry applications but that is not giving information about cell itself and how to communicate between resources e.g., robots.

Automotive industry may not need rapid changes in the cells and processes but the aerospace industry is unique in the sense of every part and its manufacturing. The need to reposition the entire robot around the part is understandable in aerospace industry as work can be done on different models in the same cell. There may be need to change the entire cell structure to assemble different parts of the wing. Hence there is a need for a completely automated and flexible system which can cater for the needs of aerospace manufacturing industry.

3 FLEXA CELL COORDINATOR

FCC is a fully automated system which receives programs and transfers it to the required resources in a controlled manner. Resource can be robot, machine, hardware or software. FCC is the part of Flexa Cell in which it is coordinating between cells and its components. It is responsible for execution of received programs in a conflict free way on the required resources. It is also important to run and manage multiple cell coordinators at the same point in time. For this purpose the use of a software Programmable Logic Controller (SoftPLC) was introduced which means there is no need for hardwired binding of resources with the cell.

The FCC receives the program outside of the system using web services in a specific format called recipe. It un-marshals the recipes and schedules it according to the availability of resources. It then activates or creates the Cell Sub Coordinator (CsC) which is having SoftPLC and the controller of the programs and resources. The controller called Programme Manager (PM) downloads the program onto the resources and gives control to SoftPLC program to control the resources and

program execution. It is also responsible of getting data back from resources (if required) and sends it back to main program of FCC called Application Manager (AM). And from here the data can send back to the resource of the recipe. The FCC is having two way communications as it accepts the data in the form of recipe and sends information back to the sender e.g., ERP system.

4 FCC ARCHITECTURE

The methodology for control and organization developed makes a number of assumptions about the process and the production resources being used. These are as follows:

1. Production is assumed to be chaotic due to the number of processes and the likelihood of concessions needing to cleared.
2. The resources (robots, machine tools etc.) can be used in different sequences for different operations either by physically relocating them or changing the root of a part through the resources.

The issues noted above mean that the use of a conventional control methodology using a Programmable Logic Controller (PLC) and a number of machines (resources) physically coupled together in a cell(s). The approach of running preloaded programmes on resources is impractical as in the cases above the individual cells would need to be physically reconfigured for each operation. A new way of approaching this problem is to use a central cell controller. That is capable of producing any number of virtual controllers which can take control of local groups of machines to form virtual cells which then behave like conventional physical cells. These CsC are software applications which are tied to their resources using a common interface. The overall cell controller is responsible for decoding recipes, allocating and scheduling resources and launching and destroying instances of the CsC when required. It also contains a database which is used to store status information to allow recovery of system status in the case of an equipment or process failure. In summary:

1. The use of a SoftPLC means that there is no longer any dedicated physical hardware associated with the cell.
2. All the production systems for example machine tools, robots or measuring systems are classed as networked resources which have a common interface which allows them to be interrogated and identified automatically.
3. When a particular production sequence is identified a 'recipe' is generated from which the required resources can be identified, allocated and programming information loaded.
4. The resources are co-ordinated using SoftPLC which is connected to the resources over a network. The overall control is provided by a cell co-ordinator which allocates a virtual CsC for each cell. Once the task is finished then the virtual CsC is closed and all the resources are freed up and made available for other tasks that may be waiting for resources.

A diagram showing the structure of the cell coordinator is shown in figure 1. The individual elements of the architecture have the following functions:

1. Application Manager (AM): It is responsible for the control of the FCC. It has responsibility to activate the FCC and communicate between the FCC's components. It also has responsibility to communicate with the rest of the world via the web services layer.
2. Scheduler: This is needed to schedule the task among resources. The Scheduler will be able to identify the available resources and will allocate the task to them according to the recipe (sent from FDB). The Scheduler will also be able to resolve and avoid conflicts (Deadlocks, etc).
3. Status Database and Monitor: The Cell coordinator status database is used to record the status of the resources available and the availability of resources (if they are available for handing over to a task). The status database monitor has active two way connection with the status database monitor which monitors all the activities of the resources and records the status of all the current recipes.
4. Recipe Queue (RQ): It accepts the request from the AM to execute a particular recipe, if there is one present. The recipes will be sent out for execution by the scheduler on first come first serve basis.
5. CsC: It is comprised of a PM and the SoftPLC. The PM receives the recipe from Scheduler and delivers programs to the resources(s). The Soft PLC also takes its program from PM and controls the resource(s) accordingly. There can be multiple CsCs all of which will be

controlled by the AM. One CsC will work with one set of resources and each other one will use a different set of resources.

6. Recipe is the XML file which contains the configuration of recipe files i.e., resource programs. There are a number of ways to set up the recipe. It can point programs from other recipes as well. A single recipe can run in one CsC and collaborate with other CsC.

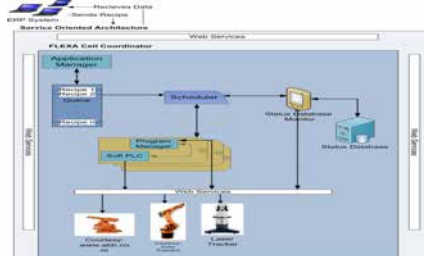


Figure 1: FCC Architecture.

5 FCC FEATURES

Main interface displays the summary of the FCC. It presents numbers about the recipes (their details), CsC, and resource status. Figure 2 shows the main interface for the operator of FCC.



Figure 2: FCC Main Interface

FCC features are highlighted in figure 3.

1. Supporting multiple cells concurrently
2. Storage of recipes and scheduling
3. Runtime resource management
4. Adding resource into the cells runtime
5. Complete logging and tracking of the system using database management system
6. Capability of restarting the system after recovering itself from error
7. Resource sharing
8. Simple and friendly user interface for operator
9. Adding cell into the FCC system on runtime
10. Distributable control

Figure 3: FCC Salient Features

6 DESIGN OF FCC

The biggest challenge in designing a flexible control system with varying cell resources is to design a loosely-coupled structure without losing efficiency and yet the system should also be easy to reconfigure and extend. Since the cell resources usually come from different manufacturers and use different platforms and communication protocols the traditional distributed computing technologies such as COM (Component Object Model), could lead to very tightly a coupled relationship between cell resources. Any changes to the system such as a newly installed metrology system may need some alterations within the original software which significantly reduces flexibility and re-configurability (Pires & Costa, 2000).

It was therefore proposed that a SOA would be more efficient. An SOA uses a web service as the basic element. This was originally designed to support interoperable machine-to-machine interaction over a network (Aphrodite & Thomi, 2002). A web service is platform-independent as it uses the standardized Simple Object Access Protocol (SOAP) as its communication protocol (Newcomer & Lomow, 2005). As a result, any device that supports TCP/IP communication can be programmed to

provide a web service which greatly reduces the complexity of communicating with different platforms and environments.

7 FCC TESTING

Testing the FCC system proves its strengths and flexibility. It has been tested in various ways such as (i) support of multiple resources, (ii) adding / configuring resource while FCC is running, (iii) support of multiple cells concurrently, etc. SoftPLC was managed to recognize the system and operate all of the resources inside cell. FCC was able to send and receive recipes for all of the cells and was able to create instances of CsCs for all of them. Figure 5 shows how SoftPLC manages multiple cell coordinators concurrently. This is the test which we run in the real cell figure 4 shows the original cell.



Figure 4: The Original Cell

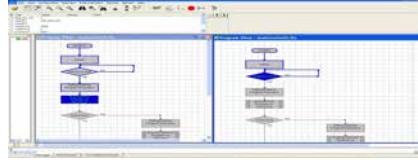


Figure 5: SoftPLC Controlling Resources in Multiple Cells

7.1 Test Case 1

Cell Coordinators 2, Resources 4 (R1: KR200 with clamping end-effector, R2: NM45, R3: LEICA Laser Tracker, R4: H4 with Drilling end-effector)

R1, R2, R4 belongs to CsC 1, R3 belongs to CsC 2

Communication ontology: Cell 1 $\leftrightarrow$ Cell 2

Purpose: To test the capability of FCC between multiple resources and cells.

Scenario: The task was to do drilling on a nominal part. R2 was doing the pre and post inspection of the part. R1 was picking the part from loading bay, putting it on the jigs & fixture and then putting it on delivery bay. R4 was responsible for drilling on the part and R3 (virtually in separate cell) was checking the position and feeding its result to the R4 for getting the right position. Figure 6 shows the FCC cell described in this scenario.

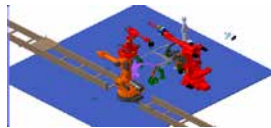


Figure 6: FCC Test Cell

Process: Recipes were sent for these cells. Recipes were received by AM and queued in RQ. After checking the resource availability recipes were picked up by FCC Scheduler (one at a time) un-marshalled and scheduled. Two respective CsCs were created which includes the PM and SoftPLC. Programs were transferred to respective CsCs. PM downloaded the recipe's programs on the resources. Programs were then waiting signal from SoftPLC to get it executed. Program which was dealing with R4 for drilling was scheduled after the completion of pre-inspection by R2. The data was sent back to the PM by the resource's (R2) program which was then transferred to the cell coordinator and then drilling task was carried out by R4. Cell #2 was also activated along with drilling. R3 was constantly checking the position of R4 and giving its feedback to Cell # 1's PM which is passing information to R4 for getting the accurate position. R4 (Cell # 1) and R3 (Cell #2) are communicating constantly via their PMs. R1 lifted the part from loading bay and put it on delivery bay after the completion of drilling process. At the end R2 did the post inspection of the part. Every cell's resources were controlled by their respective SoftPLC and the PMs. After the completion of process data was sent back to AM of FCC. The AM then forwarded the data to the source of recipes i.e., ERP. Complete process was logged at every step.

7.2 Test Case 2

Cell Coordinator 3 (includes 2 cells from test case 1), Cell #3 Digital I/O (acting as four different resources for testing purposes) R5, R6, R7, R8

Communication ontology: Cell 1 $\leftrightarrow$ Cell 2, Cell 3

Purpose: To test the capability of FCC across multiple cells on multiple locations.

Scenario: The test case 1 along with an additional cell which was physically distributed and placed on different location. R5, R6, R7, R8 were the lights attached to Digital I/O which flashed one by one.

Process: The same process was followed by CsC 1 & 2 which is detailed in the process of Test Case 1. The CsC 3 gives respective signal to SoftPLC to control R4, R5, R6 and R7. All of these resources light up when activated by corresponding physical switch. CsC 3 worked independently as it did not need to communicate with any other cell. The rest process is same as described in test case 1.

Table 1: Test Results

	Resources	Cells	Operation Time *	Errors	Total Time **
Test Case 1	4	2	12 μ sec	0	20 sec
Test Case 2	8	3	168 μ sec	0	75 sec

* Operation means the execution of recipe on the resource under the control of Soft PLC

** Total time means time taken for all of the processes of FCC i.e., receiving of recipe, un-marshalling, scheduling, executing it on resources and sending result back.

The time of the completed operation was calculated carefully by using internal time calculation routine which is double checked by using system stop watch. The test case results show that system was able to execute the recipes successfully on the FCC without any errors.

8 CONCLUSION

As proved in the section above FCC can control multiple cells and collaborate in between them. Multiple cells can work independently as well and the can also be controlled by FCC as proved in Test Case 2. There are multiple scenarios which are tested with FCC but because of the space issue all of them cannot be illustrated here. In short FCC is fully capable of managing, coordinating and controlling cells. It becomes more cost effective with resource sharing and scheduling system.

ACKNOWLEDGMENTS

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Knowledge and Information Management for Product Development

INVITED PAPER

**MAKING AUTOMATION PAY - COST & THROUGHPUT TRADE-OFFS IN THE
MANUFACTURE OF LARGE COMPOSITE COMPONENTS**

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ABSTRACT

The automation of complex manufacturing operations can provide significant savings over manual processes, and there remains much scope for increasing automation in the production of large scale structural composites. However the relationships between driving variables are complex, and the achievable throughput rate and corresponding cost for a given design are often not apparent. The deposition rate, number of machines required and unit production rates needed are interrelated and consequently the optimum unit cost is difficult to predict. A detailed study of the costs involved for a series of composite wing cover panels with different manufacturing requirements was undertaken. Panels were sized to account for manufacturing requirements and structural load requirements allowing both manual and automated lay-up procedures to influence design. It was discovered that the introduction of automated tape lay-up can significantly reduce material unit cost, and improve material utilisation, however higher production rates are needed to see this benefit.

Keywords: Composites, Cost, Automation, Trade-offs.

1 INTRODUCTION

The introduction of automation to the production of large scale composite structures has mostly been applied to individual manufacturing stages to aid processing time and cost, and improve quality and consistency. For example, current standard practice in aerospace is to trim raw ply materials using computer numerical controlled (CNC) cutting equipment, and inspect components using robotic non destructive testing (NDT) systems. Lay-up processes are however lagging behind other aspects of composite manufacture. This is partially due to the very significant capital costs associated with the equipment needed, and typically higher recurring costs. However, these automated machines can be operated with minimal labour and can yield better consistency and precision than the equivalent manual processes.

But the picture is complicated, and the headline figure of kilograms per hour as the deposition rate depends on both the capability of the equipment and the size of the component. Consider for example Automated Tape Laying (ATL). The more capable machines allow deposition at higher advancing speeds, and larger components provide longer deposition paths, allowing greater distance which in

turn permits the machine to achieve its maximum deposition rate. This technology is still developing, hence the maximum rates are still behind what is needed for true high volume throughput.

The question then is: *“When needing to go into production how does the design of the panel (i.e. the volume and geometry of material) and the manufacturing process proposed interact, and therefore what resource produces the maximum output for that design?”*

Using a single carbon-fibre epoxy material this question is addressed by studying the design and manufacture of a typical wing cover. Both manual and automated lay-up processes are studied with each design cognisant of production process. Non-recurring and recurring costs are also obtained.

The following sections give some basic background and context on the material, design, and manufacturing processes as well as the implications on cost, before moving on to the methodology and results obtained.

2 BACKGROUND AND CONTEXT

Before elucidating on the actual design and costing methods, it is useful to identify key aspects for consideration in the choice and usage of the material systems, the key design considerations (which should include manufacture) and the general process considerations (which also link to design).

2.1 Material Considerations

Composite material systems come in several formats from individual fibre and resins to more sophisticated pre-impregnated fabrics (pre-preg). Typically processed material systems such as pre-pregs or woven fabric are used for large components to reduce manufacturing time, but this brings with it additional cost. The other trade-off with such woven fabrics is that fibre crimping and reduced fibre volume fraction tend to reduce in-plane strength and stiffness. Non-crimp fabrics are structurally superior, consisting of several consolidated uni-directional layers. They also carry additional cost. Woven fabric, non-crimp fabric and unidirectional tape are all provided in roll form and are well suited to manual lay-up. However, in the case of ATL only unidirectional tape is usable.

Research into the costing costing of raw composite materials has been limited. A few publications of note including Goss 1986; Cinquin 2001, clearly identify that the material itself, and the precursor are the main drivers. In industry this is recognised and the best avenue for price reduction is through long term contracts and competitive tendering. As this is the key element, contract pricing is used in these studies, although it is non-dimensionalised.

2.2 Design Considerations

Typical wing structures consist of stiffened panels, that is an external skin stiffened by longitudinal (spanwise) and lateral (chordwise) stiffeners. These panels are subject to impact damage, and as they are thin they may exhibit instability which must be checked for during design. Since the panels are typically designed and analysed in small sections, neighbouring elements may have differing thicknesses. In manufacturing ply continuity must therefore be carefully maintained across these boundaries. Such structures may also require a repair at some point so, panel repairs which include mechanical fasteners must also be accounted for. Interestingly, the thickness of the repaired panel drives the size of the fastener, which can constrain the width of the structural element.

The design of panels in this way can also cause stress concentrations due to different thicknesses across boundaries (Saresta et al 2007) which require methods to blend adjacent segments (Yamazaki 1996; Kristinsdottir 2001). These can both improve ply continuity and reduce stress concentrations. Genetic algorithms are often used to help here (Kristinsdottir 2001; Seresta et al 2007), but the most common industrial method, and the one used herein is the use of a pre-defined library of compatible stacking sequences. This approach has been demonstrated to keep mass down but maintain ply continuity (Niazi 2006).

2.3 Manufacturing Process Considerations

There are many processing options available in the steps to produce a composite part, from preparing raw material through to curing the final part shape. Autoclave production is most common for aircraft

primary structure manufacture. Thus the studied wing cover is assumed to be autoclave cured using invar tooling.

Costing of such processes and the range of approaches available is wide, and unlike the material itself, there are many studies on costing for composite component manufacture (Curran 2004; Kauffman 2011; Bader 2002; Schubel 2012; Kendall 1998). Manufacturing costs in most studies do not model production volume as a variable, but all noted that material utilisation was a key driver. Schubel (2012) examined wind turbine blades and production volume, identifying that costs do fall rapidly up to 400 parts, but level off above 1000 parts per year. In this case automated processing takes twice the production volume before reaching a plateau, due to large initial capital cost. It is outside aerospace that the true advantages of automation are seen, as per Kermo (2000) and Kandella (1998). These give some indication that perhaps the same savings through automation may not be achievable in aerospace with lower production volumes.

3 CONFIGURATION DESIGN, ANALYSIS AND STUDY METHODOLOGY

As indicated above design and manufacturing are tightly linked and therefore a combined methodology is required. Each structure must be redesigned to suit the manufacturing process used, so that the appropriate constraints are imposed and the wing structure designed correctly.

3.1 Structural Configuration, Constraints and Materials

The chosen configuration is an upper wing cover for a single aisle aircraft. It has 118 individual skin-stringer units with a fixed rib pitch of 700mm and variable stringer pitch (165-300mm). The loading is idealised into 19 zones as per Figure 1 (Quinn 2012, Mullan 2012). Compression buckling is not permitted at less than 130% limit load. The stacking sequences are all balanced and symmetric. Skin ramp rates are kept at 1:10 chordwise, and 1:20 spanwise.

A laminate material library was generated using ply properties, the Tsai-Hill failure criterion and a simple empirical knockdown factor of 40% (Renieri 1981) to obtain damaged and part allowables.

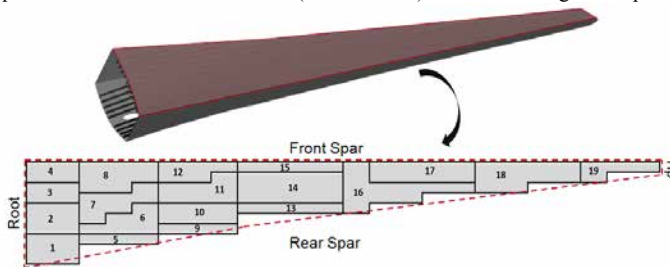


Figure 1 – Upper wing cover loading zones.

3.2 Structural Design

The structure is further idealised as a series of plate and column elements, and sized using standard aerospace check stress methods including;

- Static strength of skin and stiffener sections under compression and tension loading.
- Static strength of skin sections under shear and combined tension and shear loading.
- Uniaxial and biaxial compressive skin buckling, skin shear buckling and combined compression and shear buckling.
- Stiffener cross sectional buckling and crippling.
- Stiffener compressive Euler buckling and combined flexure and local crippling using both Secant and Johnson-Euler methods.
- Combined stiffener axial compression and lateral pressure using beam-column analysis methods.

An automated sizing tool developed in-house was used for all design and analysis work. The basic process is to generate a design space from all combinations of geometry and material; and the component design satisfying the appropriate constraints for the chosen manufacturing process.

3.3 Manufacture & Manufacturing Costs

For the studies it was assumed that the lay-ups would consist of pre-preg unidirectional plies (0,90,+45,-45) and non-crimp fabrics (± 45 & 0,90), and for ATL unidirectional tape. With manual lay-up it is assumed that de-bulking occurs after the first ply, and every three subsequently. After lay-up the component is sealed in a vacuum bag and cured in the autoclave at $\sim 180^\circ\text{C}$ for 8 hours. The skin is cured before co-curing the stiffeners to create the final component.

An activity based costing approach is used to obtain costs for this manufacturing process, in conjunction with contract pricing and industrial labour data (Mullan 2012). It is assumed that all ATL equipment is solely for manufacture of the wing cover. Amortisation is based on utilisation factors estimated from real production data and is calculated over the life of the production run. The production route using manual layup is shown in Figure 2 (using ALT the cutting and layup operations are replaced with a single ALT layup process).

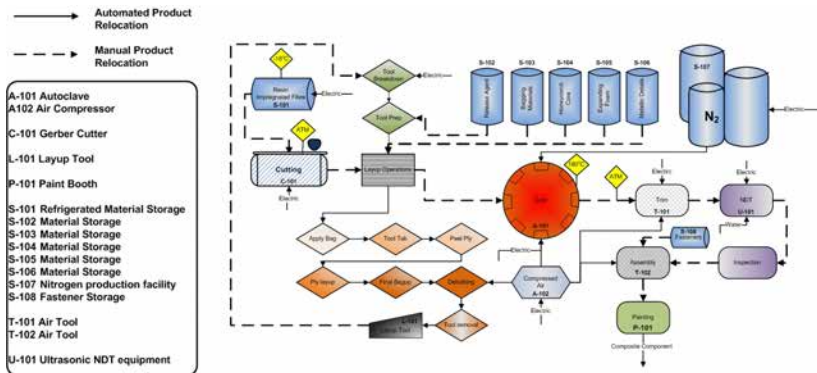


Figure 2 – Composite component production using the hand layout (HLU) process.

4 RESULTS AND DISCUSSION

In order to compare the two manufacturing processes two different designs were produced to match the freedoms and constraints of the layup processes, the key characteristics of which are summarised in Table 1. For the cost analysis of each design the production was based on a three shift pattern with a two year return on investment period for the ATL equipment. Deposition rates were varied from 3 kg/hr (standard HLU rate) to 30 kg/hr (current limit of ATL commercial technology). The target was for a maximum of 140 wing sets per annum.

Table 1: Trade-study design spaces.

	ATL-0.50	HLU-0.50
Skin		
Materials	Uniaxial tape	Uniaxial and Biaxial NCF fabric
Composition	40/40/20 $\pm 10\%$	40/40/20 $\pm 10\%$
Guide laminate	$[[+45/-45/0/90/0]_9]_s$	$[[\pm 45/0,90/0]_9]_s$
No. of laminates	39	39
Thickness increment	0.5mm	0.5mm
Stiffener		
Materials	Uniaxial and Biaxial NCF fabric	Uniaxial and Biaxial NCF fabric
Composition	50/40/10 $\pm 10\%$	50/40/10 $\pm 10\%$
Guide laminate	$[[90[0_2/\pm 45/0]_2]_3]_s$	$[[90[0_2/\pm 45/0]_2]_3]_s$
No. of laminates	13	13
Thickness increment	0.5mm	0.5mm

4.1 Results for Component Designs

The key design results are shown in Table 2. There is very limited difference in the weight of the optimised ATL and HLU designs (0.25% based on the lighter ATL solution). As would be expected the ATL solution features a greater number of plies and ply drops.

Table 2: Component designs.		
	ATL-0.50	HLU-0.50
	Skin	
Mass (kg)	367.5	368.3
No. of plies*	316	77
No. of ply drops	54	34
	Stiffeners (12 off)	
Mass (kg)	204.7	205.3
No. of plies*	792	792
No. of ply drops	217	215
	Wing cover	
Mass (kg)	572.2	573.6

* The total number of physical plies including for HLU splicing due to material roll width limitations.

4.2 Results for Costs

The key cost results are shown in Table 3. Three key results emerge:

- the ATL solution has a lower unit cost (13.8%).
- the material costs are lower for the ATL solution (due to lower raw material prices and higher material utilisation).
- the overall plant cost are a factor of 1.63 higher for the ATL solution.

Table 3: Component unit cost breakdown.		
	ATL-0.50	HLU-0.50
Optimum maximum equipment deposition rate	23 kg/hr	---
Number of ATL machines	1	---
	Skin	
Material	0.377	0.583
Labour	0.013	0.026
	Stiffeners (12 off)	
Material	0.316	0.317
Labour	0.066	0.066
	Wing cover	
Energy	0.012	0.012
Plant	0.218	0.134
Total	1.000	1.138

Figure 3 illustrates the results of the cost study when production rates are increased and additional ATL machines are brought online to increase throughput. This interesting result illustrates that lower overall cost may be achievable with fewer ATL machines but the deposition and production rates need to be much higher to see the benefits.

5 CONCLUSIONS

The study focused on comparing the costs for large composite panels manufactured using hand lay up or automated tape layup methods and compared the resulting designs and costs for both. Analysis of the results have shown that the optimum cost is a function of the minimum deposition rate and the minimum number of ATL machines needed to meet the production rate. The costs have step changes

at points and hence are highly sensitive at these junctures to small changes in either the design, the production rate, or the deposition rate. Good understanding of these boundaries and the interaction of the chosen production method with the final design of the product, is therefore clearly needed to achieve the benefits promised by automation technology, or equally importantly, simply to understand the costs being incurred by design or production decisions.

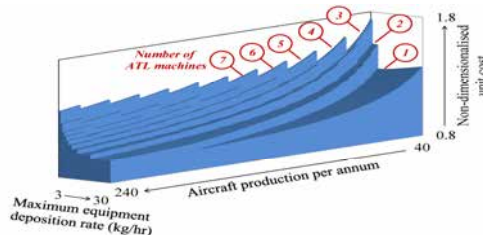


Figure 3: Unit cost analysis results with varying production and deposition rate.

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FIGHTERS PILOT HELMET DESIGN FOR 5TH GENERATION AIRCRAFT

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ABSTRACT

Fighter pilots' helmets have become more complex and heavier resulting in long term implications to pilots musculoskeletal systems as they fly and experience high g-load. Current research has identified design changes to the helmet to accommodate the ancillary items fitted to assist pilots but at the expense of comfort and additional loading. Its manufacturing requirements and adaptations to offer bespoke solutions are addressed to allow for training and operational usage. To produce the next generation of helmets that reduce long-term injuries, from g-loads and asymmetrical ancillaries requires individual considerations, unique manufacturing requirements and the ability to support with service spares anywhere in the world at short notice. This paper will describe how manufacturing requirements are matched to ergonomic needs and bespoke components can support global demands.

Keywords: Pilot helmets, Bespoke manufacture, Global support.

1 INTRODUCTION

Hard helmets for military pilots were designed and issued when the jet age started place higher g-loads and more extensive training. Prior to the jet age Spitfire pilots were using leather helmets with the stereotypical goggles and silk scarves, more to keep warm than for protection, Roussel, M. (2013). To meet the high demands of jet fighters pilot training became extensive and expensive. It became apparent that to protect their investment in training the pilot heads needing protecting too; thus hard helmets were used that incorporated the oxygen, communication and anti-glare systems. These were of a fibre glass based design to maximise protection at a minimum weight. This classic type of helmet was used extensively throughout the world's military and incorporated in most military cockpits. Pilots were reporting unfit to fly due to neck strains and these were compounding to result in the long term issues, Anderson (1988). Procedures in training any flying were introduced, for example, g-warm, where warm up manoeuvres similar to the idea of sports people before matches.

The rapid expansion of electronics and software in the 1980s produced a wide range of equipment that offered operational advantages to pilots. Night Vision Glasses, NVG, being perhaps the most prominent example that could give air-to-air superiority in combat in a dog-fight or evasive low level flying. NVG weighs vary from anything between 1 – 2 kg and are attached to the side or overhead of the helmet for easy of deployment at a short notice, Lange, *et al.* (2011). Designs of helmets were changed and counter weights added to compensate the asymmetrical loading. Such situations are not a problem for general use adding some weight, albeit there are limits that certainly vary for individuals

and different missions. However, consider the operational requirements of fighter pilots for both training and conflict. Most pilots fortunately will not have to be in a real life-or-death dogfight, their training has to incorporate this aspect and low level, low speed manoeuvres that result in high g-loading situations. Combine this to long-term exposure, operational flying will be in the region of 12 years before senior ranks that limit flying time, to high g-loads on their neck and upper body and the musculoskeletal problems increase, Newman and Kaloupek,(2004). The very product deigned to protect the pilot is now the most likely feature to cause injury and even end a pilots career. To protect a pilot, the investment in training, ensuring pilots are fit for deployment is now dependent on the aircraft and also the most suitable helmet for 5th generation aircraft.

2 DESIGN REQUIREMENTS

A fundamental review and redesign of the helmet is needed if the issues resulting from current fighter aircraft are not replicated on modern 5th generation pilots and issues addressed and minimised. These modern 5th generation fighter aircraft have more extensive manoeuvring capability than the previous ones, require more training and operational use to maintain currency and this all goes to increase the risk of musculoskeletal damage to pilots NASA (2010). They are designed to operate at higher g-loads and manoeuvres in advanced of current aircraft and other nations 5th generation aircraft.

Intermediate solutions for high neck loading has been proposed, some similar to those in Formula 1 and Indy racing. It has to be added here that securing a helmet to the frame is not an option. Constantly looking in all aspects of flight that are visible, rotating the aircraft to allow for broader visual horizons and checking for situational awareness must not be compromised De Loose, *et al.* (2009). Any new design of helmet needs to be a self-contained head mounting unit that is free standing. Assuming NVG will drastically reduce in weight is not realistic, see figure 1 below. New designs are more efficient and capable, so if anything can be assumed they will at best stay the same weight but with improved capability.



Figure 1: A helmet with NVG.

Traditionally helmets have been sized according head size (small, medium or large), with limited bespoke allowances and internal strap adjustment to maintain a comfortable fit. A webbed inner section does allow for comfort and a form of shock absorbent action and air circulation. It does, also, add an extension to the mounting point of any asymmetrically loaded additions. This added space will further increase any applied bending moment to the pilots musculoskeletal system. A space of just 25 mm increases the torque loading on a spine for a typical 2 kg NVG system by 25%, Craig (2013).

Figure 1 above show that combining this weight with the face mask and any further ancillary items will likely compound this loading, which further exacerbate musculoskeletal risks to pilots.

Current thought of design is to add more to the helmet, figure 2 below. Even if these could be symmetrical in weight and balance the applied torque in a g-load will place strain on the pilots necks and upper body. When items are developed they may improve, what they do not do is keep to the original specifications and compromises are made in fit, function and cost. Current fighter pilot helmet design has evolved and been developed from the initial ones first used at the start of the jet ages. These developments have not reached, probably exceeded, the limits of operational use for long-term musculoskeletal damage to pilots.



Figure 2: A 5th generation pilots helmet.

Fifth generation pilot helmets must now incorporate more than head protection and the standard array of additions. To address musculoskeletal risks for the pilots in both every day and long-term there are now issues to add to helmet design: light weight, ability to withstand impact, reduce asymmetrical loading of additions, a platform for any specific addition, not interfere with operational use requirements and comfort. Unlike many designs the cost is of secondary consideration.

3 ERGONOMIC CONSIDERATIONS

Human head dimensions do vary as considerably as other body parts in their ratio. The height of a head does not change significantly from 15 years old to adulthood. Nevertheless, the principal feature for helmet design is based on the maximum width of the head just above the ears and the sellion to the back of the head. The tables below show the principal dimensions in inches for men and women for both these physical features.

If you consider that the three main sizes currently used as the shells then accommodating these with internal adjustable straps then there is a large level of variation between pilots, Wickens *et al.* (1997). As mentioned above this unnecessary space between the webbing and the pilots head, or at least keeping it to a minimum can drastically reduce loading on the pilots musculoskeletal system. This has to now be considered a core requirement for 5th generation aircraft pilots.

Table 1: Head breadth dimensions for men and women in inches.

	1 st	5 th	50 th	95 th	99 th
Men	5.1	5.6	6.0	6.3	6.5
Women	5.2	5.4	5.7	6.0	6.1

Table 2: Head length from sellion to back of head for men and women in inches.

	1 st	5 th	50 th	95 th	99 th
Men	6.7	6.8	7.3	7.8	8.1
Women	6.1	6.4	6.9	7.4	7.6

Considering these two tables, there are variations in head width of 1 inch from the smallest woman to the largest man. Whilst there is also an inch difference from the sellion to the back of the head. It can, and should, be argued that it is the time for bespoke helmets for every pilot but also a unique design for operation use. For example, why not have a separate helmet for day flying as well as night flying, or a separate one for just flying where minimum loads will be applied externally as would be used in simple flights, performance checking, etc. A helmet that has its maximum weight is only used when in combat and sometimes in combat training.

4 MATERIAL SELECTION AND DESIGN

Taking the starting point as a bespoke helmet, for day, night, standard non-combat and combat flights it results in the need for four helmets to suit all operational usage. In order to suit individual requirement a design is needed that will be comfortable (which can vary from person to person), incorporate communications, life support systems, head protection and ancillary equipment, Lui, *et. Al.*, (2006). The 5th generation of fighters are being designed to incorporate 360° vision with camera projection onto a face screen.

Sports science has made parallel developments in head protection and none more than in the area of cyclists, see figure 3 below. Professional cyclist helmets can have weights below 250g, which if compared to a basic pilot's helmet without any ancillary parts weigh in excess of 1.5 kg. Yet, they are designed to do the same, minimise head injuries in low impact incidents. No helmet will save a life where high loads and speeds are involved or in excessive shock loads to the skull. Even if they could protect the skull at high loads the neck is unable to be protected and fatalities will result. A helmet must protect the head although this will have limitations.



Figure 3: Lightweight cycle helmet.

These designs for cyclists are a generation ahead of standard pilot helmets and if the aim is to reduce long-term head and neck injuries then any design must supply equipment that is commensurate with expectations. Clearly, these designs can use advanced materials and manufacturing techniques that are now available. These are available to include directional laminates on foam based lining that model the pilots' head fully.

Light weight composites can be manufactured in bespoke configurations providing there is a pattern. The helmet can be built up layer by layer until it is the appropriate thickness for the corresponding requirements. Individual designs, applications and materials can be matched to suit pilots' needs. After all, Formula 1 seats are uniquely moulded to support individual driver comfort

and assist in reducing the upper neck loads experience when g-loads are experienced in fast turns and overtaking, this may be an extension need to be further added to compliment the next generation of helmets.

5 MANUFACTURING ISSUES

Any bespoke helmet, regardless of material, will need a pattern. Previously this would have required individual methods to be taken manually and a wooden pattern hand made. This was traditionally how gentlemen's hats were produced, and the pattern (mould) kept for any new or replacements. Co-ordinate measuring machines and computer controlled milling machines allow for fast turnarounds to develop the patterns in a wide variety of materials. This is the basis needed to make a composite lattice structured of multi-layered parts. Three dimensional moulds for composite mould can be produced quickly with 3D printing, any changes likewise can also be incorporated in real time.

Laser based Co-ordinate measuring Machines, CMM, can scan a head and profile to process the data for 3D printing or machining at any manufacturing facility in the world. A true bespoke helmet can be achieved rapidly from composites, and according to the individual requirements. Layered composites and head/foam protection as the frame is possible to be combined that will hug the head profile, allow air-flow for comfort whilst still performing all the operational requirements of current pilot helmets. Skeletal external frames that allow for air-flow, localised mass to secure ancillary items can be matched accordingly. It can offer any of the four potential types recommended to be match in minimum weight.

It is feasible that a standard helmet for basic flying, transportation between regions and routine maintenance checks could be below 1 kg even with communication and life support systems. The heaviest helmet will always be the full system for high end training and combat flying. Nevertheless, the weight can be reduced, loads reduced and thus reducing the potential immediate and long term risks to the musculoskeletal system.

Composite layering also allows for directional strength to be localised where maximum stress or loads will be expected, Autar (2005). This has the advantage of allowing for weight loss in other areas and keeping the overall weight as low as possible. Composite layering over a bespoke foam skeletal frame is the fundamental that may have the most significant influence on long-term problems for pilots. The matching of these aspects to bespoke design is paralleled in research with the material selection and design for 5th generation fighter pilot helmets.

6 LOGISTIC PRACTICALITIES

If a pilot needs four helmets to support full requirements and any accident, knock, damage or incident will require a replacement; it will not be possible to acquisition a standard replacement form any localised stores. This raises the question of if there should be a standard emergency replacement as it would seem pointless not to have an available fighter aircraft, pilot but not operational due to no helmet, Wallenburg (2011). Each type would need a local spare as any critical aircraft part. Incorporating this is a minor exercise although one that needs organisation as any other.

Emergency replacement for helmet replacement would be accomplished by replacing the spare that has been acquisitioned and minimise the replacement, logistics of getting to a critical zone. Alternatively, having localised manufacturing sites allied to deployments will offer assistance. If this is not suitable, practical and logical the fall-back can be the existing options for emergency use to suit a couple of combat sorties.

7 CONCLUSIONS

This paper has addressed the needs for 5th generation pilots helmet designs and requirements. The focus of this work has been to reduce the long-term risks to the musculoskeletal system of pilots that has implications to end a fighter pilots career early, and hence all the investments in time and money.

It has addressed how current designs have been less than adequate and will fall short for current requirements. It has proposed that there should be four helmets to suit flight requirements. These subsequently can be manufactured using advanced and real time methods; spares produced and incorporated into the standard list of operational

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QUALITY FUNCTION DEPLOYMENT AND SENSITIVITY ANALYSIS OF REQUIREMENTS FOR FUTURE AIRCRAFT PROPULSION CRYOGENIC COOLING SYSTEMS

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ABSTRACT

A number of novel future airframe and propulsion concepts are considered in order to meet aviation targets set by various aviation regulatory bodies including NASA and the Advisory Council for Aeronautics Research in Europe (ACARE). The current NASA concept for long-range civil aircraft is the Blended-Wing Body (BWB) aircraft, coupled with turbo-electric distributed propulsion (TeDP), to enable a host of efficiency benefits over current designs. NASA has identified superconducting technology as a key enabler to deliver this airframe. Superconductors need to be cooled to cryogenic temperatures for normal operation. Using a sensitivity matrix, it was found that the Exchange Heat and Transport/Pump Cryogen functions are the most sensitive to input variation. The failure modes and effects analysis performed on the functional model show that the detection functions are critical during component failure. Quality Function Deployment (QFD) analysis shows the Exchange Heat and Transport/Pump Cryogen functions are also critical.

Keywords: Systems Engineering, Cryogenics, Distributed Propulsion.

1 INTRODUCTION

As global aviation popularity perpetuates itself and as hydrocarbon fuels become increasingly scarce, there is a fervent requirement for more efficient ways for aircraft to achieve similar or better performance compared to current designs. NASA has outlined a specific set of targets shown in Figure 1 with regards field length, fuel burn, and emissions including noise and NO_x (Kim, Brown, and Felder 2008). Many ways of achieving this are being considered in order to meet the specified N+3 targets, with the current best preferred method considered being turbo-electric distributed propulsion (TeDP) (Kim 2010).

Corners of the Trade Space	2025* (N+3) Technology Benefits
Noise Emissions	71dB Reduction
LTO NO _x Emissions	>75% Reduction
Aircraft Fuel Burn	>70% Reduction
Field Length	Metrex Concept Exploitation

* For a technology readiness level between 4-6

Figure 1: NASA's ARMD N+3 Subsonic, Fixed Wing Targets (Kim 2010).

TeDP comprises of a gas turbine driven set of generators which distribute power to a set of electrically driven fans, typically spread across the trailing edge of any lifting surface. This potentially offers many benefits including boundary layer ingestion (BLI), higher lift-to-drag ratio, and a higher overall bypass ratio, meaning shorter field lengths and lower fuel consumption (Kim 2010). TeDP is made possible by recent advances in superconductivity and materials, whereby extremely high power densities can be achieved within superconducting electrical networks and machines where previously

Figure 2 shows the functional model of the cryogenic cooling system previously generated. The model was validated by discussion with three groups of stakeholders, with two experts from each group included to minimise bias risk. The groups chosen were research aerospace, research electrical, and systems electrical. They were each chosen due to their stake in the project at this early stage; other stakeholders are yet to be involved, however at this level of technological maturity, it is preferable to maintain simplicity. The functional model shown was generated for one of five modes, the ‘Maintain Temperature at Load’ mode of operation. This was highlighted as most critical in operation due to the number of mission profile segments that fall within the mode (Palmer, Shehab and Husband 2012). As each mode is different in functional operation, each diagram is unique in terms of how it manages the inputs of the system. This model is used throughout the study, and although it is subject to further iteration, it can be assumed to be true for the current phase of analysis.

4 FUNCTIONAL MODEL ANALYSIS

4.1 Sensitivity Matrix

Figure 3 shows the sensitivity matrix for the model shown in Figure 2. The matrix shows that there are two areas of high sensitivity with a large number of affecting inputs and affected outputs. These are the ‘Exchange Heat’ and ‘Transport/Pump Cryogen’ functions. Although it may seem obvious from the diagram that this is the case given the number of inputs and outputs, their sensitivity to variation is not apparent. This is clearly evident by observing the ‘Monitor Temp/Press’ function, which is relatively insensitive despite a high number of inputs/outputs.

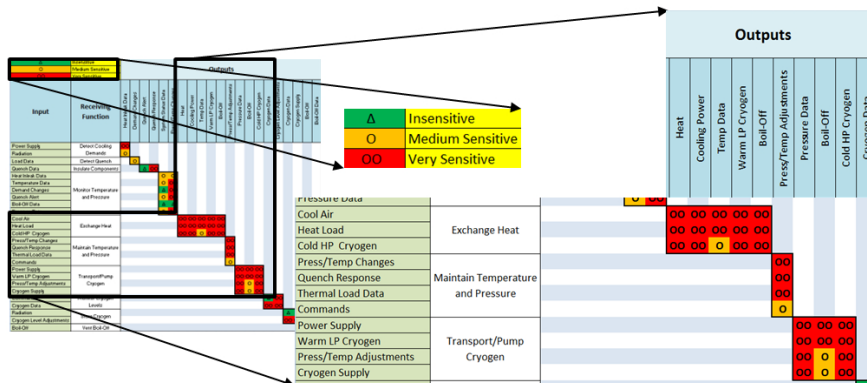


Figure 3: Flow sensitivity matrix for the ‘Maintain Temperature at Load’ mode.

There are other areas of sensitivity shown in the sensitivity matrix, mainly the ‘Vent-Boil-Off’ and ‘Monitor Cryogen Levels’ functions. These are both sensitive to variation, however as the ‘Vent Boil-Off’ function has only one input/output; it is not considered a major area of sensitivity at this stage. The ‘Monitor Cryogen Levels’ function can be considered sensitive due to the nature of the function; its function is to be sensitive to input variation, therefore its sensitivity is a desirable trait. Another area of variation affected in the same way as the ‘Monitor Cryogen Levels’ function is the ‘Maintain Temperature and Pressure’ function, whereby its purpose is to affect another function, and as a result appears sensitive, however as the function is designed to be, it can be assumed insignificant.

4.2 Failure Modes and Effects Analysis

Figure 4 shows the FMEA for the functional model. Three of the functions have been selected as of key interest, which are the ‘Detect Cooling Demands’, ‘Detect Quench’, and ‘Vent Boil-Off’ functions as each of these were recorded as high risk; however the reasons for this are varied. The two

functions that enable detection are viewed as critical due to their functional nature; should the system not be able to 'detect' in the way they are designed, this would constitute not only a whole system failure, but possibly permanent damage to the cooling system and its dependant systems. The functions high risk (marked in red, Figure 4) can be explained by considering the functions themselves and the tasks they must perform; if a 'detect' function fails, then detection of that failure or any other problem becomes much more difficult.

Function	Functional failure mode	Effects	S	Causes	O	Current Detection Method	O	RPN	Design Suggestions	New O	New RPN
(2) Detect Cooling Demands	Sensors not working	SC system Quenching	8	Faulty sensors, damaged sensors, system damage through maintenance	5	Thermocouples, capacitance thermocouples, thermistors	10	80	Use multiple sensors for high redundancy	1	80
	Cryogen flooding and/or excessive cooling	Cryogen flooding and/or excessive cooling	6		5		10	300		1	60
	Sensors giving wrong readings	SC system Quenching	8		5		10	80		1	80
	Cryogen flooding and/or excessive cooling	Cryogen flooding and/or excessive cooling	6		5		10	300		1	60
	Wrong demand interpretation	Excessive or inadequate cooling, loss of cryogen	7	Software error, sensor damage	2		10	140	Software checking needed, with high rate of redundancy on processing	1	70
(3) Detect Quench	No/incorrect quench data	SC system Quenching without knowledge, system overheats and permanent damage occurs	9	Faulty sensors, damaged sensors, system damage through maintenance	2	Thermocouples, capacitance thermocouples, thermistors, (boil-off measurement?)	10	180	High sensor redundancy, software maintenance	1	90
	System not quenching, but flooded/shut down for no reason	System not quenching, but flooded/shut down for no reason	7		2		10	140		1	70
	Quench Not Detected	Permanent SC System Damage	9		2		10	180	High sensor redundancy	1	90
(10) Vent Boil-Off	boil-off unable to escape	Possible cryogenic system rupture, loss of cryogenics	10	Venting system failure, 'sticky' valves, trapped contaminant blocking valves	3	Pressure sensors	9	270	Method for detecting contaminant required		0
	excessive cryogen boil-off	Early depletion of cryogen	6	Open 'sticky' valve, valve malfunction	2	Valve pressure sensors	10	60	High-reliability valves needed	1	80

Figure 4: FMEA for the Functional Model.

Due to the temperatures involved, the failure rate or probability must be considered high as at this stage in cryogenics, reliable, robust sensors have not been developed. This is expected to change as technology and requirement for such sensors advances, which coupled with a high rate of redundancy, effectively manages the risk of a detection failure.

The 'Vent Boil-Off' function is also highlighted as a key area of interest due to its potential consequences and its difficulty of detection. The interest in this functional failure arises from its cause and detection; current cryogenic systems will not have to operate in varying environments, and as a result, contamination or foreign object presence probability is increased. Furthermore, there are no known methods for detection of such failures until damage has occurred; hence a need is identified for an active monitoring system for both the boil-off and vacuum systems necessary.

4.3 Quality Function Deployment

Figure 5 illustrates the QFD analysis 'House of Quality' (HoQ) diagram. Normally whilst performing a HoQ diagram, the customer requirements and functions have target performance values, however because of the very early stage of this type of concept, values are not known, hence they are omitted.

The first notable point of interest within the HoQ is the Low Weight requirement and its comparatively low overall importance score, despite having a customer importance factor of 5. Although highlighted by stakeholders as the overall key issue, it scores low due to its independency of the systems functional operation. If the system is lighter, it does not mean that the system necessarily performs the task better; however it will impact the aircrafts overall efficiency, hence the result can be adequately explained.

The highest scoring factor was the Availability/Reliability requirement, which was selected by all stakeholders involved as a key requirement. This shows that each function must perform its task reliably for the system as a whole to function as designed. This may mean however that the reliability requirement is too broad; future iterations of the HoQ could include subsections within reliability such as redundancy, low failure rates, and certification maturity.

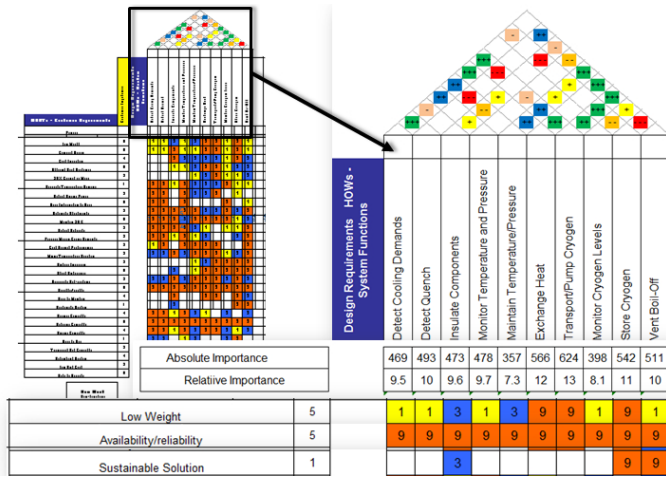


Figure 5: QFD House of Quality key points.

The final point of interest is the ‘Sustainable Solution’ requirement, which was selected as the most potentially needless requirement. Sustainability is important, although not selected as key at this stage; however the HoQ has shown it to bear little impact on the system functionality. This is similar in nature to the Low Weight function, whereby the functions of the system may not necessarily represent the overall requirement for a sustainable solution because it does not impact functional performance.

The absolute performance factors for the HoQ show that the most critical function is the ‘Transport/Pump Cryogen’ function, with the ‘Exchange Heat’, ‘Store Cryogen’, and ‘Vent Boil-Off’ functions also all scoring highly. This agrees with the sensitivity matrix, highlighting that the highest system criticality lies in less than half of the overall system functionality.

5 CRYOGENIC TECHNOLOGY

There are many possible options regarding the method of cryocooling for superconducting aircraft propulsion systems, however many of these are currently too heavy or bulky. Although some weight can be saved by replacement of industrial technology and materials for aerospace optimised versions, some technology is essentially never going to be sufficient for purpose. This likely will include any form of reciprocating compressor driven coolers, such as Gifford-McMahon (G-M) and Pulse Tube, due to their sizes and weights. Considering the N3-X concept machines are optimistically predicted to be 99.97% efficient, at an 80 MW full load this equates to 24 kW of cooling power at 25 K (Felder, Brown, and Kim 2009). Using the commercially available CryoMech AL325 G-M cold head with the CP1010 reciprocating scroll-type compressor, this would roughly mean an overall weight increase of 234 kg per 100 W of cooling power; roughly 60 tonnes of equipment (CryoMech Inc. 2013).

Assuming an 80% reduction in weight as optimisation (Palmer, Shehab and Husband 2012), we can assume the system could be delivered at 12 tonnes in a more compact design, however when also considering the required power input at 11.2 kW per compressor, the combined power required for operation of 2.68 MW returns an overall efficiency of 96.64%. As the cryocooler design is running at 9% of Carnot efficiency, even if NASA’s target of 30% of Carnot is achieved, this still represents an efficiency of 98.92%, over a 1% drop in overall efficiency. This is considerable as this cannot be sufficiently mitigated with aerospace technology to be viable, while also not considering the extensive incidental equipment required for operation. The cryogenic system weight of 12 tonnes adds 50% of the proposed weight of the electrical system in the best case theorised by NASA (Felder *et al.* 2011).

This brief analysis effectively rules out the use of reciprocating compressive technology for use within superconducting aerospace propulsion applications at this stage.

Currently preferred by NASA are reverse-Brayton cryocoolers, with some examples already in use for aerospace applications (Felder *et al.* 2011) (Hill *et al.* 2007). Options regarding cryogen cooling are also being considered, with liquid hydrogen possibly providing a tenable solution due to its convenient temperature range and high thermal capacity, both latent and specific heat.

6 CONCLUSIONS

From the analysis of the functional model it can be seen from both the sensitivity matrix and HoQ that the 'Exchange Heat' and 'Transport/Pump Cryogen' functions are most critical, with both exhibiting high sensitivity and strong relationships with the overall requirements outlined by stakeholders. This is in accordance with Pareto's 80:20 principle, whereby in this case around 80% of the critical functionality comes from just 20% of the functions.

Use of the FMEA at this stage is confirmed as significant, due to the generic nature of the project and the FMEA's nature of suggesting design mitigations for functions despite the need to maintain independence from solutions; however the approach serves some purpose in highlighting the detection functions as those requiring high redundancy.

Cryocoolers must undergo a revolution if they are ever to make their way onto aircraft for cooling of superconducting propulsion systems, as they are still too bulky, heavy, and inefficient. There are methods of mitigating their efficiency, for example by the addition of heat sinks with cryogen cooling, however further analysis on the effect of compound systems must be performed in order to confirm this. This does not mean reciprocating compressors may get a new lease of life; they will likely be superseded by rotary versions of higher power density, in much the same way and for similar reasons that the internal combustion engine was replaced by the jet engine.

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AN INTELLIGENT APPROACH TO DESIGN THREE-DIMENSIONAL AIRCRAFT SHEET METAL PART MODEL FOR MANUFACTURE

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ABSTRACT

Aircraft sheet metal part manufacturing is a knowledge-intensive process, and the manufacturability and manufacturing information are required to be considered in three-dimensional (3D) model by knowledge reuse. This paper presents a 3D model structure of the aircraft sheet metal part and an intelligent approach to design the model for manufacture combining intelligent manufacturability analysis with manufacturing information definition. Processability of part, formability of material and cost of fabrication are proposed to analyse the manufacturability of the part. Knowledge base for manufacturability analysis is established, and knowledge is reused to evaluate the part's manufacturability intelligently to meet the constraints of manufacturing conditions. Non-geometric information is defined in the 3D model to meet the needs of digital manufacturing and inspection using model-based technology. An example is given to describe the process of design for manufacture, which shows that the approach can realize the concurrent design and digital manufacturing of aircraft sheet metal.

Keywords: design for manufacture, intelligent manufacturability analysis, knowledge reuse.

1 INTRODUCTION

Sheet metal part is an important component of aircraft. Typical aircraft sheet metal parts include frame and rib parts, skins, panels, etc. Aircraft sheet metal parts and their manufacturing technology have such properties as complex structure, complex definition, difficult forming and difficult coordination.

Currently, digital design and manufacturing technology has been widely used in the development of aircraft products. Most of the manufacturing cost is defined during the design stage, and many of the quality characteristics are also fixed when the design stage is accomplished. So the different needs of the whole process should be considered for comprehensive descriptions. Related researches mainly focus on taking manufacturability analysis into design process by DFM(Design for manufacture) and MBD (Model Based Definition) technology.

In order to ensure the part's manufacturability and reduce design changes of sheet metal part, designers should consider the manufacturing requirements in design model. The manufacturability evaluating indexes should be decomposed in different design stages to analyse the part, which will

make design and manufacture concurrent. DFM technology is one of the key technologies of concurrent engineering, its purpose is to fully consider the feasibility of downstream manufacturing sectors in the design stage (Ferrera et al. 2009). Li (2008) proposes a method of reading engineering information from the PDM system, interacting the parts classified information through the user interface, at last combining all kinds of information to analyse the manufacturability evaluating indexes for manufacturability analysis. Knowledge utilizing is to solve the manufacturing problem in manufacture engineering chain through using knowledge. In some manufacturing activities, such as process planning (Wang et al. 2007) and manufacturability analysis (Cochrane et al. 2008), knowledge retrieval is performed based on similarity of product or process. However, existing DFM methods mainly emphasis on the manufacturability analysis of the parts which are completely designed, it's not common to integrate DFM technology into the design process.

In order to meet the requirements of digital manufacturing and inspecting, designers should build 3D model for manufacturing. The 3D model should include non-geometric information expressed in traditional drawings, such as dimensions, tolerances and inspection information. MBD technology is based on the definition of the model (Lu et al. 2008 and Alemanni et al. 2011), Zhou et al. (2008) explain the meaning of MBD, propose a definition of digital coordinating products, 3D digital technology design, 3D data organization management and 3D digital process integration applications. Existing research about the MBD method mainly carried out from macroscopic views (Quintana et al. 2010). However, the 3D model of sheet metal part consists of geometric elements, manufacturing requirements, etc. So researching on the model with dimensions and tolerances needs further studied.

This paper proposes an intelligent approach to definite 3D sheet metal part model for manufacture. Three manufacturability evaluating indexes are proposed to evaluate the manufacturability of part based on the manufacturability knowledge base. Geometric information is defined in the guidance of DFM technology to meet the process constraints, non-geometric information is defined in the 3D model based on MBD technology to meet the needs of digital manufacturing and inspecting.

2 3D MODEL FOR MANUFACTURE OF SHEET METAL PART

Typical aircraft sheet metal parts have different structure features. Frame and rib parts consist of web, flange, joggle, lightening hole, etc. Skin and panel parts consist of matrix, gaps, stringers, etc. Figure 1 shows the 3D model of sheet metal part for manufacture, including geometric information and non-geometric information. Geometric information includes the shape of the parts and the dimensions transformation during manufacturing process. Non-geometric information includes annotations and attributes of parts.

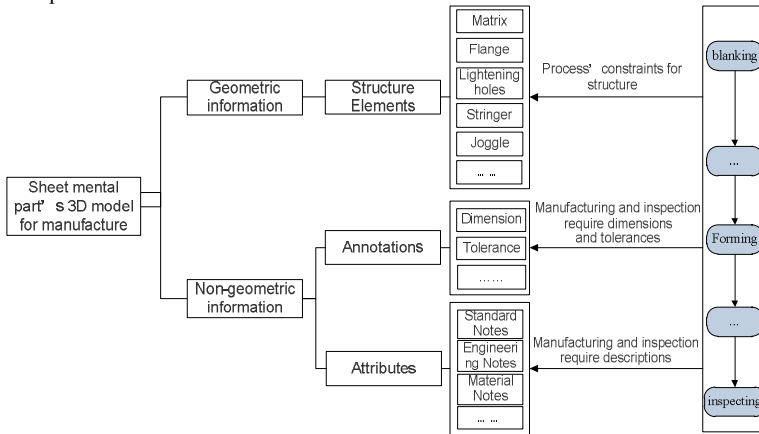


Figure 1: Information structure of the 3D model for manufacture

Annotations are divided into dimensions and tolerances. Dimensions mainly refer to the sizes of structure elements. Tolerances include the accurate information of structure elements and the accurate relative position between different structure elements. Attributes do not display as annotations in the 3D model, they exists as text descriptions of manufacturing and inspection information, which can be obtained by querying in the model. Some manufacturing information such as standard description, part management information, technical requirement, material description, approval or release information is suitable to be expressed as attributes, which contribute to the standard and orderly manufacture.

3 INTELLIGENT DESIGN FOR MANUFACTURE

3.1 Flow of intelligent design for manufacture

Figure 2 shows the intelligent design flow of frame and rib part. Considering the whole design process of part, the structure features are taken as the mainline and defined one by one. Geometrical information is defined within the manufacturing constraints. The constraints are supported by the knowledge base, which is built by process engineers for storing the knowledge including enterprise standard, specification, manual and experience. Moreover, with the support of tolerances and standards knowledge base, dimensions, tolerances, attributes, and other information are defined to meet manufacturing and inspecting needs. Intelligent manufacturability analysis of structure features and manufacturing information definition are combined.

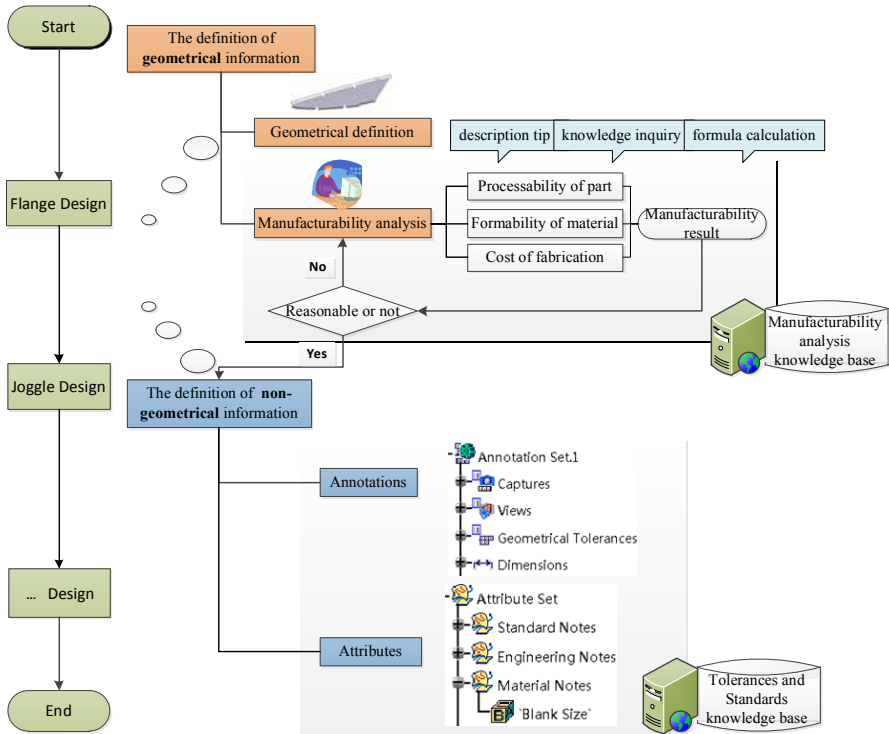


Figure 2: Intelligent design flow of frame and rib part.

During the stage of manufacturability analysis, the structural parameters of the part are acquired firstly, then the manufacturability evaluating indexes are calculated by the support of knowledge base.

At last a conclusion is drawn to explain whether the manufacturing is feasible and economic. For the parts whose manufacture process are unreasonable, the manufacturability result is used for the modification of design.

Manufacturability evaluating indexes are established in this paper to evaluate whether the manufacturing process is reasonable. Table 1 shows the three kinds of manufacturability evaluating indexes of sheet metal part. The processability of part means that the dimensions of the sheet metal part should be in the range of the workbench and the forming force should be within the limit of the machine's existing capacity so that the part can be formed on the specified machine. The formability of material means that the forming parameters of structure elements should be within the forming limit of the given material so that the material will not be destroyed in the manufacturing. The cost of fabrication means that the structure elements should meet the standard requirements to reduce the quantity of special tooling so that the cost of fabrication can be controlled in a perfect range.

Table 1: Manufacturability evaluating indexes of sheet metal part.

Content	Parameters as examples
Processability of part	length, width, height of part
Formability of material	limited bending radius, minimum thickness
Cost of fabrication	layout and dimension of structure elements

Manufacturability analysis of sheet metal part relates to many kinds of knowledge such as part features, standards, machine parameters, material forming limits and so on. Knowledge base for manufacturability analysis is established according to the three evaluating indexes. The technology of knowledge reuse is introduced to combine the knowledge base with existing general CAD systems.

3.2 Structure element design for manufacture

The intelligent design approach of 3D model for sheet metal part is divided into two stages, geometric definition and non-geometric definition. During the geometric definition stage, structure features are created through querying the knowledge base, which provides structural standards and sizes requirements. In the geometric model, designers could check the layout between structure features and the sizes which belong to the structure features. It turns to the non-geometric definition stage when the part meets the manufacturing requirements, and designers could define the dimensions and tolerances. Otherwise it will return back to the geometric definition and designers should find the reasons and redefine the geometric information. The intelligent design system of sheet metal part for manufacture is developed based on CATIA CAA. The system could standardize the design flow of part, and make the manufacturability analysis embedded in the design process which realizes part design quickly and concurrently. This intelligent design system consists of structure elements modules. The knowledge base is applied based on Web technology.

Flange design for manufacture is shown in Figure 3. A variety of parameters are evaluated to judge the manufacturability including bending radius, bending angle, flange height. For instance, the value of bending radius should be more than the minimum bending radius. Then bending coefficient is verified to complete the creation of geometric features. At last, dimensions and tolerances are defined to complete the definition of non-geometric information.

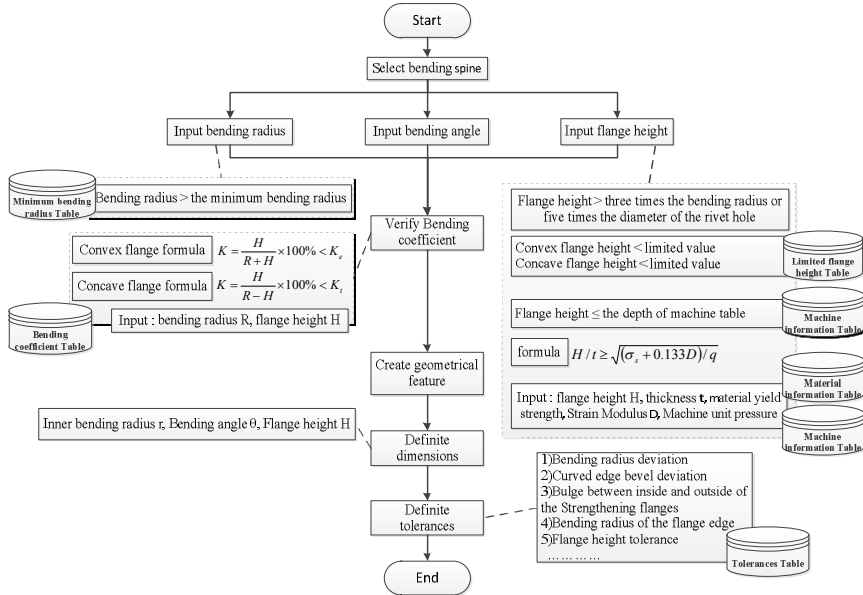


Figure 3: Flange design for manufacture

Figure 4 shows that flange parameters such as bending radius, flange height and bending coefficient are evaluated in the intelligent design system to realize the design for manufacture. As for bending coefficient analysis, designers could click on the ‘Calculate’ button to get result directly as bending radius and flange height have been automatically extracted in the TXT box. And a web page appears as ‘Bending coefficient Table’ button is clicked. The page provides the standard bending coefficient value, which could be compared with the calculating result. Similarly, another web page will provide the tolerances requirements when clicking on ‘Tolerances Table’.

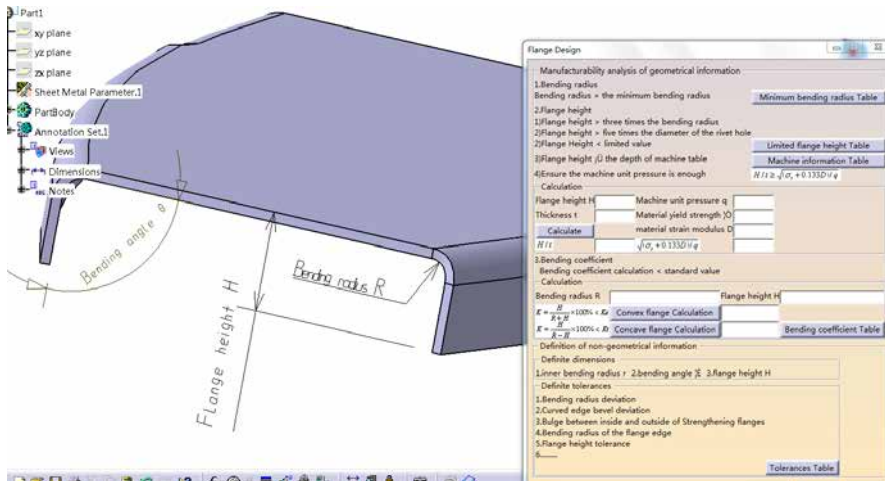


Figure 4: Flange design in the system

4 CONCLUSION

In this study, an intelligent approach is proposed to design 3D aircraft sheet metal part model for manufacture. Advanced technologies such as DFM and MBD are applied to integrate the design process with manufacturing information. This approach can realize the concurrent design and digital manufacturing. An example is used to verify the effectiveness and practicability of the approach. With the achievement of this study, the design of sheet metal part will be more efficient and accurate. Geometric information is created with the constraints of manufacturability and it will reduce the rework of design. Detailed non-geometric information is defined in 3D model to suffice the digital intelligent manufacture of new aircraft products.

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LEAN PRODUCT DEVELOPMENT PERFORMANCE MEASUREMENT TOOL

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ABSTRACT

The need of applying lean thinking to product development is becoming a must for the organisations to success in the current industry. This paper presents a tool that helps to define the actual status of the organisations in relation to the lean principles. Extensive literature highlighted the need of developing a tool focused on assessing the implementation of lean principles themselves, rather than quantitate metrics. Based on the Balanced Scorecard, four perspectives, with corresponding set of questions, were defined reflecting the enablers of the product development model proposed by the LeanPPD European project. A five-level scale was customised to score the different readiness levels that define the transformation into a full lean implementation. The tool was used to assess the current and desired lean situation of an aerospace company within the research environment and resulted to be accurate to define the starting condition of the company to adopt leaner practices.

Keywords: LeanPPD, Lean Transformation, Lean Assessment.

1 INTRODUCTION

Continuous pressure on product development due to rapid changes in customers' demands forces companies to seek for more cost effective and time efficient improvements. Lean thinking improvement philosophy is a potential way to be followed in order to enhance the performance of the process of product development. There has been a previous research towards applying lean thinking in product and process development (PPD) by structuring the five core enablers of LeanPPD. Namely, list them here (Khan, et al., 2011b). In this paper these enablers set the four perspectives of a LeanPPD Performance Measurement Tool.

It is recommended that before implementing lean thinking in product development there is a need to measure the readiness of the enterprise in order to adapt lean into the current processes. The available tools that aim to measure performance are concentrated on financial aspects, and these do not consider strategy and improvements, and do not assess the product development processes. Therefore this paper addresses this need by developing a novel tool to measure current product development processes comparing them to the best case lean scenario. Thus this article presents the development of a Lean Product and Process Development Performance Measurement Tool and also discusses one case study within the research environment of an aerospace company.

2 RELATED LITERATURE

The ‘Lean Product and Process Development’ (LeanPPD) project, supported by the European Commission, analysed the different approaches followed by the research community to come up with a new product development model: The LeanPPD Model (Khan, et al., 2011b, Al-Ashaab, et al., 2013). This model based on lean thinking considers the entire product life cycle, providing a knowledge based environment to support value creation to the customers. The LeanPPD Model consists of five enablers: Value Focus, Knowledge-based environment, Continuous Improvement, Chief Engineer and Set-Based Concurrent Engineering (Khan, et al., 2011b).

Set-Based Concurrent Engineering (SBCE) is the core enabler of the model as it is the process that guides the Lean Product Development. The other four are embedded or support the process (Khan, et al., 2011b). The approach of Set-Based Concurrent Engineering defends that products are developed by breaking them down into subsystems and designing sets of solutions for them in parallel. Testing and communication with other participants narrow down the sets gradually, until the final solution is obtained. This makes sure that enough knowledge is created to support the decisions and the selections are not rushed like in many cases (Al-Ashaab et al., 2013, Sobek, et al., 1998).

The SBCE principles have been extracted from the following references: Sobek, et al., 1998; Sobek, et al., 1999; Morgan & Liker, 2006; Ward, 2007; Kennedy, et al., 2008; and summarised in Figure 1.

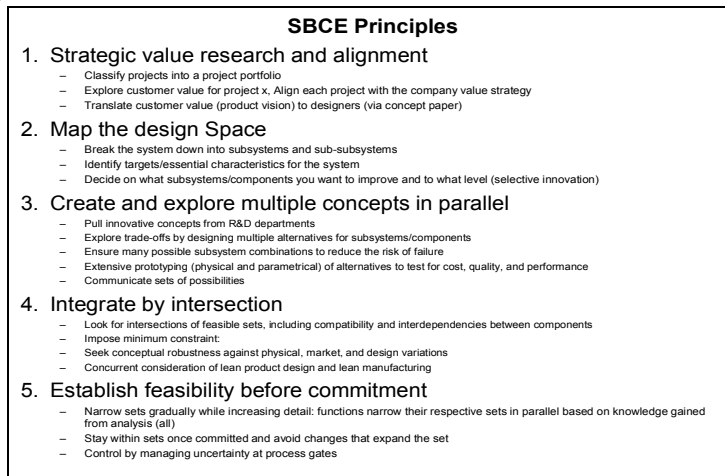


Figure 1: Set-Based Concurrent Engineering Principles

One of the tools used for performance measurement to monitor the success of an organization is Key Performance Indicators (KPIs). They are quantifiable measurements of critical factors that reflect the organization’s goals on a long-term consideration (Jovan & Zorzut, 2006). Another commonly used tool is the Balanced Scorecard (BSC), which was designed as a management decision tool providing a simple framework of balanced set of measures to link strategy and operational performance (Kaplan & Norton, 1992).

A research performed with the involvement of academics and industrial representatives (Pawar & Driva, 1999) showed the concern and importance of measuring the performance in product design and development, for instance the comparison between the real and the projected completion time, time to market, or number of trials before the production obtained a usage over 50%. These results are reinforced by other authors, which adds variables like quality of the product, novelty or management satisfaction (Barclay, 2002; Krishnan & Ulrich, 2001; Driva, et al., 2001), among others. However, all of these methods intended to measure the results obtained by a company but do not consider the

product development process itself, and therefore cannot be customized to assess the applications of the lean thinking principles.

Within the Lean Thinking environment, Haque and Moore (2004) developed a set of metrics derived from lean manufacturing to adapt them into the lean thinking application in new product introduction (NPI). Their approach to promote lean thinking came up with a number of quantitative ratios that could help measuring performance and progress (e.g.: total value of engineering output versus cost of engineering department, non-compliances versus number of requirements.). These metrics are useful to identify if a company is obtaining the results of a theoretical successful implementation of lean principles in product development. Though, they do not focus on the process itself, and therefore, are unable to give evidence of the principles being actually embedded or not.

The authors found only two tools that partially measure the lean thinking application in product development. The research performed by the Lean Aerospace Initiative (LAI) came up with the LAI Enterprise Tool Triad (Perkins, et al., 2010), composed by the Lean Enterprise Model, the Transition To Lean Roadmap, and the Lean Enterprise Self-Assessment Tool (LESAT). The scope of the LESAT covers all key product lifecycle processes and is divided into sections (Lean Transformation/Leadership, Life-cycle Processes, and Enabling Infrastructure) with their corresponding subsections. It uses a generic 5 Lean competence scale that describes the maturity of the process.

Another initiative was developed by Lockheed Martin Aeronautics Company from the US. Their Lean Scorecard is a self-assessment tool to measure the maturity of the Lean implementation within their practices (Lockheed Martin Aeronautics Company, 2009). It provides a set of 8 components (Leadership, Transparency, Lean Product Development, Process Focus, Just-In-Time, Process Control, Standard Work, and Continuous Improvement) and their sub-components, together with 5 maturity levels, customized for each sub-component, to measure the Lean transformation.

The review of the literature has revealed that some of the presented tools and methods could help to measure certain aspects of Lean Thinking in product development. However, even if some have shown up as being on the good track, there is no suitable tool to accomplish the performance measurement of the Lean Transformation from all its different points of view like the process, the knowledge, the value or the continuous improvement. Therefore, there is a need of defining the requirements of the tool that would address this issue.

3 THE DESIGN OF THE LEANPPD PERFORMANCE MEASUREMENT TOOL

As the reviewed literature has identified a gap, there is a need for a new tool to measure the lean thinking application in product design and development. This measurement needs to reflect the key enablers of the LeanPPD enablers as shown in Figure 1, as well as address the key principles of Set-Based Concurrent Engineering listed in Table 1.

The authors agreed that the tool should enable the companies to identify their status in the Lean transformation by providing them with a readiness framework. The tool would also provide a template to report the results highlighting strengths and weaknesses, as well as improvement areas.

The authors adapted the structure of the Balanced Scorecard by identifying four perspectives to reflect the key areas to be measured, as listed below with the relative weight:

1. Product Development Process (30%),
2. Tools (15%) and Enablers (15%),
3. Knowledge Focus (29%),
4. and Continuous Improvement (20%).

The first perspective, Product Development Process, mainly reflects the Set-Based Concurrent Engineering. Intending to simplify the tool and due to their direct relation, two other enablers of the LeanPPD Model have been included in this perspective: Chief Engineer and Value Focus. The Chief Engineer is the technical leader that manages and leads the whole development process, and on the other hand, the aim of the process is to maximise the value of the product developed. The Tools and Enablers perspective is those key elements that need to be within the key activities of the SBCE to enable the performance of the task within that activity. This will address different elements such as requirements definition, value definition, design for manufacturing, risk assessment or functional modelling. The third perspective is Knowledge Focus because lean product development is product

development in knowledge based environment (Maksimovic, et al., 2011). The fourth perspective is Continuous Improvement. The authors believe that LeanPPD is a continuous improvement via solving problem to create a knowledge environment.

However, unlike in the Balanced Scorecard, the four perspectives have different weights in the overall LeanPPD Performance Measurement Tool. The reason behind this is that the authors defend that product development cannot be performed without a well-defined process with its corresponding tools and enablers. However, product development can be done without having a formal initiative of knowledge management and continuous improvement. This has been acknowledged and approved by the industrial partners. Therefore, the loads of the different perspectives are 30% for Product Development and for Tools plus Enablers, and 20% for Knowledge Focus and for Continuous Improvement.

Each perspective of the LeanPPD Performance Measurement Tool contains a concrete number of questions. The composition of these questions enables the companies to self-assess the journey of the lean thinking application in their product design and development.

The approach taken in this research is that there are five lean readiness levels which form the SAUCE (Start-Awareness-Unstructured-Continued-Evolved) scale, and are shown below.

1. S – Start: The company does not apply the lean practices in its Product Development Process
2. A – Awareness: The company is aware of the benefits brought by the lean practices but does not have any formal method to implement them
3. U – Unstructured: The company has started implementing the lean practices in its PDP following an informal method
4. C – Continued: The company has implemented the lean practice into its PDP at some specific stages following a formal method
5. E – Evolved: The company has implemented the lean practices into in all the stages of its Product Development Process following a formal method

Once the questions are given scores and the perspectives are weighted, the current (AS-IS) level and the desired (TO-BE) level of product development processes of a company can be assessed.

In this section, an example of questions of the different perspectives is presented in order to illustrate how the principles of LeanPPD and SBCE are covered in the performance measurement tool. It is part of the innovative approach of the authors that the questions have been asked without a direct use of the key words of the LeanPPD and SBCE. This leads to less confusion when measuring current processes. For example, within the Product Development perspective, in order to reflect one of the practices of SBCE, one of the questions asks about how the conceptual design is selected, as it is shown in Table 1.

Table 1: Question related to the practice of Set-Based Concurrent Engineering

Q 1.10	How do you select the conceptual design solution that will be developed?
1	We only produce one solution for each component or subsystem.
2	We only produce one solution but we are aware of the benefits of multiple solutions.
3	We identify multiple solutions, and select the solution based on a subjective assessment (experience, previous projects...).
4	We identify multiple solutions, and select the solution based on a objective assessment (tests, prototyping...).
5	We initiate the design of multiple solutions in all projects, and gradually rule out the weaker solutions based on the knowledge gained from simulation and/or physical testing.

4 LEANPPD PERFORMANCE MEASUREMENT CASE STUDY

This section presents the work that had been done in one company from the UK aerospace industry and shows the examples on two perspectives, Product Development Process and Knowledge Management.

The authors performed the performance measurement of the product development process through face-to-face interviews to 15 representatives from different areas, such as: product designer, manufacturing engineering, product assembly planning, project management, purchasing, and supplier technical assistant. The results were captured individually and then it was made an average from their results.

The overall results of the performance measurement of the company show that company's product development AS-IS processes contain elements that are considered lean but are not yet part of a formal method. Moreover, the expected future level shows a totally lean product development process in all aspects, represented by score 5 and putting the company in the Evolved stage of the SAUCE scale. These overall results are the average of the separate results of the four perspectives.

The measurement regarding the AS-IS level of the product development process principle is detailed by a list of the questions and the results can be exposed in a diagram as it is shown in **Figure 2**. The company identified that the formal product development model is followed in specific stages (Q 1.2) but the communication of the process model needs to be improved (Q 1.1). The company believes that the manufacturing engineers are involved in the product development (Q1.5) although the formed multifunctional teams do not retain the same members from beginning until the end of the project (Q 1.6). Moreover, manufacturing suppliers are mainly involved once the final design concept is selected (Q 1.11).

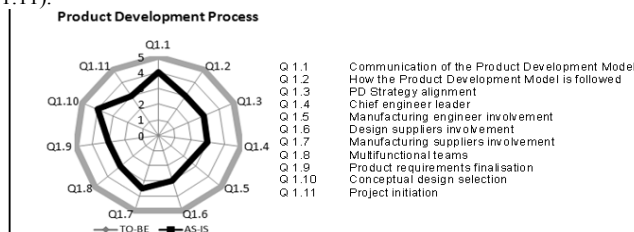


Figure 2: The product Development prospective results of the aerospace company (modified for confidentiality reasons)

The results of the assessment, presented in **Figure 3**, reflect that the company has already initiated a methodology for knowledge capture, re-use and creation (Q 3.1); however, they are aiming at the full implementation of a knowledge management program. Currently engineers identify the experts through their experience (Q 3.2), which does not assure that the right person is always contacted. Therefore the company has identified the importance of creating a skill directory to facilitate this task. The lessons learnt during the projects are captured at the completion of them and a strategy for further optimizing their use has been suggested (Q 3.4).

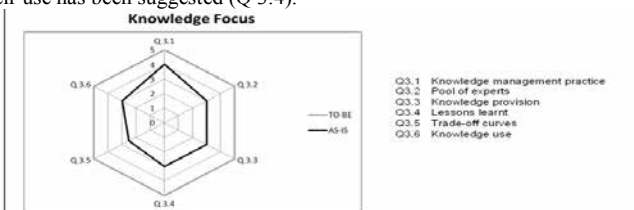


Figure 3: The Knowledge Focus perspective results of the Aerospace Company in a radior diagram (modified for confidentiality reason)

5 CONCLUSIONS

This paper has presented the development of a tool to assess the performance of the lean thinking application in product development through measurements that reflect the key enablers of LeanPPD. The tool is composed by sets of questions, arranged according to the LeanPPD enablers (knowledge, continuous improvements, value focus and SBCE.) and SBCE principles, which provide a well-defined framework to study all product development practices in detail by focusing on aspects such as

the value, the knowledge or the continuous improvement. The LeanPPD Performance Measurement tool has been used in one company from the aerospace sector within the research environment, to evaluate its current situation in the lean journey. The analysis of the results is identifying the areas of improvement in its product development models to make it more robust by implementing lean thinking practices.

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THE INFLUENCING MECHANISM OF MANUFACTURING SCENE CHANGE ON PROCESS DOMAIN KNOWLEDGE REUSE

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ABSTRACT

It is necessary for a enterprise to reuse outside process domain knowledge to develop intelligent manufacturing technology. The key factors influencing knowledge reuse in digital manufacturing scene are manufacturing activities and PPR (Products, Processes and Resources) related to knowledge modeling, enterprise and integrated systems related to knowledge utilizing. How these factors influence knowledge modeling and utilizing is analyzed. Process domain knowledge reuse across the enterprises consists of knowledge reconfiguration and integrated application with CAx systems. The module-based knowledge model and loosely-coupled integration application of process domain knowledge are proposed. The aircraft sheet metal process domain knowledge reuse is taken as an example, and it shows that the knowledge reuse process can be made flexible and rapid.

Keywords: Knowledge reuse, Knowledge reconfiguration, Integrated application.

1 INTRODUCTION

Modern manufacturing technology is becoming intelligent to make organizations respond rapidly and perform flexibly. To modern enterprises, it is necessary to develop intelligent manufacturing technology by integrating computer-aided system with knowledge-based system based on process domain knowledge reuse. Effective reuse of enterprise knowledge is a key strategic component of product development (Rezayat 2000). Design reuse in product design is typical research direction (Alizon et al. 2006). Knowledge reuse framework in digital manufacturing consists of correlated knowledge modeling and knowledge utilizing (Liu et al.2012). The knowledge-intensive aircraft manufacturing processes are divided into different process domains such as metal cutting, metal forming, and assembling and so on. Correspondingly, process domain knowledge has the characteristics of various types, different sources and complicated structure, and is different from the knowledge of solving a single problem. Knowledge reuse is influenced by many factors in certain manufacturing scene.

Process knowledge reuse is based on the determination of knowledge classification and composition. To various types and complicated structure knowledge, knowledge needs to be described from species and population. Knowledge is organized by process or task (Han et al.2009, Baxter et al. 2008 and Guerra-Zubiaga et al. 2008), but the minimum granularity is not described. As manufacturing knowledge is used to support solving problem of manufacturing tasks in product fabricating or assembling processes, classifying the knowledge by three dimensions of products,

fabricating processes and manufacturing tasks meets the requirements of information definition in product manufacturing of certain process domain (Liu et al.2012). The knowledge is further classified into basic types of minimum granularity. Different granularities of knowledge bases can be not only reused in the same enterprise, but also reused by other enterprises to make them perform better in terms of low-time and high-quality output. Current research is focusing on knowledge reuse in the same enterprise to support certain manufacturing activity. For instance, knowledge is reused in product design (Baxter et al. 2008), manufacturability analysis(Cochrane et al. 2008), process planning, product assembly (Alizon et al. 2006) etc. Similarity match algorithms are presented by many researchers. Many research organizations and enterprises have established different kinds of knowledge base and knowledge-based system. The process domain knowledge reuse across various enterprises is a new research direction. As the biology fits to environment, existing process knowledge in database needs to fit the changes of manufacturing scene to make the reuse more efficiently and effectively. These factors in manufacturing scene are required to be considered in knowledge modeling and utilizing. The reuse process and influencing mechanism of these factors on the knowledge reuse needs further research.

In this work, the influencing mechanism of manufacturing scene change on process domain knowledge reuse is built to aid the engineer during knowledge reuse across the enterprises. This paper will first establish the digital manufacturing scene and analyze the key factors in process domain knowledge reuse across the enterprises. Then, knowledge reuse framework influenced by manufacturing scene change across the enterprises is proposed and examples are given. The final section discusses the influencing mechanism.

2 KEY FACTORS INFLUENCING KNOWLEDGE REUSE IN MANUFACTURING

The information in manufacturing can be classified into product manufacturing information and manufacturing knowledge. The first one is the all kinds of information of manufacturing elements including products, processes, resources (PPR); and the second one is all kinds of knowledge, which support the design or definition the information of manufacturing elements. Digital manufacturing scene consists of the information defining and the material processing. In information defining, the engineers use knowledge to define the PPR information models, and represent the models in some information carrier. In material processing, product manufacturing is driven by PPR information to transform material into products. Different persons, parts or products, time, place, software, hardware and manufacturing tasks form different manufacturing scenes, where the inputs of information and material are transformed into outputs of parts or products. The definition, management and application of PPR information is the key to digital manufacturing or E-manufacturing.

Process domain knowledge reuse across the enterprises is to build knowledge base by reconfiguring knowledge base and integrating intelligent design tools with its existing software systems to retrieve the knowledge to form the solution to support information model definition. In order to adapt to knowledge reuse across the enterprises, knowledge modeling and utilizing approach need to respond rapidly. There is same knowledge including process terms, material data, operation descriptions etc in some process domain knowledge, and there is close or different knowledge because of different technique level, machinery, etc in manufacturing scene. Process domain knowledge is reused for different manufacturing activities in different enterprises by integrating with different software systems. On the analysis of the manufacturing scene, products, machinery, tooling, tasks, operations, software systems, persons, etc. are the factors influencing knowledge reuse across the enterprise. These factors can be classified by knowledge modeling and knowledge utilizing as follows:

(1) Factors related to knowledge utilizing: Two factors of enterprise and integrated systems determine the main scene of different departments or enterprise and integration mode separately. All tasks or activities in digital manufacturing are completed by computer-aided application systems. Knowledge base is used through integrating with software tools in knowledge-reuse enterprise. To certain task in product manufacturing, engineers utilize knowledge to solve manufacturing problems and utilize application systems to edit the information model. The knowledge is required to be composed of standard domain concepts and used in distributed environment. The knowledge-based system is required to be integrated with changing software systems across the enterprises.

Application systems are gradually implemented to meet different function requirements in enterprise, and there are variances at developing technology, data structure, operating environment in different enterprises. Different modules of the same application system require different kinds of knowledge and reasoning mode. This leads to variance at integration scheme. Through analyzing all elements in integration and integration relationships, the flexible integration application mode is required to be established.

(2) Factors related to knowledge modeling: Two factors of manufacturing activities and PPR determine the knowledge types and knowledge population or content. Knowledge is correlated centering on the product information which is constituted of three kinds of manufacturing element information of products, processes and resources in process domain and serves for all tasks or activities. When products, processes and resources change, knowledge types and elements is required to reconfigure. The classification is required to be clear and easy to be cut. The organization or structure is required to be flexible and reconfigured rapidly.

On the one hand, the enterprise to reuse process domain knowledge has established some knowledge bases including work type, process file and other manufacturing resources. The knowledge will be merged with the new selected knowledge to form process domain knowledge base. On the other hand, not all the knowledge elements need to be modified. Firstly, process domain terms can be used without modification. Secondly, typical PPR information or knowledge elements can be updated and need a few modifications. Thirdly, case PPR information or knowledge elements need to be added according to the changing conditions of PPR.

3 KNOWLEDGE REUSE INFLUENCED BY MANUFACTURING SCENE CHANGE

The process domain knowledge reuse in target enterprise A is along two routes of knowledge reconfiguration and knowledge integrated application. Firstly, on the analysis of the enterprise, the processes and manufacturing activities are determined; then the types of knowledge are selected and knowledge elements are adjusted to form the target knowledge base. Secondly, the interfaces of information integration and user are developed. In the target enterprise, the knowledge can be reused to design the parameters and information model intelligently, rapidly, and qualifiedly, and the knowledge can be best used to perform efficiently.

(1) Knowledge reconfiguration: Manufacturing activities, processes, and products that the knowledge supports are different with the enterprises to reuse knowledge. This decides that different types or granularities of knowledge will be reused. To knowledge population, the variance of PPR that constitutes knowledge leads to the changes of content of knowledge base. Knowledge reconfiguration includes top-down knowledge type selection and bottom-up knowledge population configuration. After the knowledge types are selected, the knowledge elements are changed by adding, modification and deletion to form the new knowledge population. It is a knowledge base transplantation process customized by the target enterprise demands.

(2) Integration application: The knowledge utilizing process can be divided into problem definition, design inference and solution revision. The integration of intelligent design tools with CAX systems and knowledge bases in the target enterprise concerns about heterogeneous databases, knowledge utilizing logic, process planning systems, process information base, manufacturing resource bases from database to software interface upward. Through knowledge integration application, the knowledge is utilized to define the manufacturing information more rapidly and qualifiedly.

3.1 Knowledge reconfiguration

(1) Modular process domain knowledge organization model orienting to reuse: Knowledge model is built from the viewpoint of classification to describe the layers and components in every layer and from the viewpoint of population to construct knowledge elements. Firstly, knowledge of complex product manufacturing is classified into tribe of top layer by manufacturing activities, into genus by fabricating processes, and into group by products. The three classification standards are taken as three axis, and knowledge classification coordinate system is established. The point in this coordination system represents some kind of knowledge, which is named by z, y and x coordinates. For example, the point in Fig.1 represents ribs part rubber hydro-forming flow planning knowledge. A group of

knowledge is classified into basic type by abstract degrees of manufacturing elements information. Type is the bottom classification unit and minimum granularity of knowledge, which includes special, typical and general knowledge. Knowledge element is decomposed into information elements that are made up of known features and solving features. So there are two kinds of data item in knowledge model. One is knowledge element, and the other is information element.

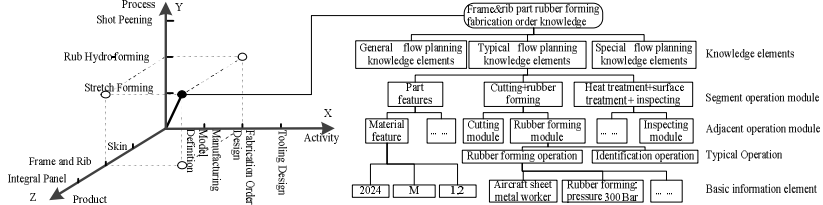


Figure 1: Aircraft sheet metal forming process domain knowledge organization model

Fig.1 shows the example of process domain knowledge organization model. Traditionally, knowledge organization is lack of flexibility and leads to the low efficiency in knowledge reconfiguration. For example, typical part fabrication process flow design knowledge is composed of dozens of separate operations. The influence of key factors has shown that knowledge organization is required to be flexible to adapt to the knowledge reuse across the enterprises. A kind of knowledge organization based on modular information elements is established. The operations in process flow can group into two layers of typical general information elements: adjacent operation module and segment flow module. The first one is membership of second one.

Module is a big granularity of information element. In the knowledge reconfiguration, module can be used to construct knowledge elements rapidly. The process domain knowledge reconfiguration is that data items are adjusted to adapt to the target enterprise. Information elements contents of operations are changed, but the fabricating flow can be constructed by the unchanged operations modules. That is to say, typical part fabrication process flow design knowledge elements can be utilized directly after the bottom operations are changed. This decreases the steps of knowledge elements reconfiguration and improves the efficiency.

(2) Knowledge reconfiguration process: Process domain knowledge types are selected to be reused based on the top-down knowledge classification tree according to the processes that the target enterprise uses and activities to support. The source knowledge population is stored in database, and database management system (DBMS) may be different from the target one. For example, the source DBMS is Oracle, but the target DBMS is SQL server. The difference should be considered to transplant the knowledge from source database to the target one.

The source data items of knowledge population are reconfigured to adapt to the changes of PPR from bottom to up. The changes consist of adding, modification or deletion of PPR information elements. The data items to be changed and the influencing paths are determined by comparison. The reconfiguration process is from bottom basic information elements, medium granularity of information elements to up knowledge elements layer by layer. Firstly, Adding new basic information or domain ontology. The terms of product, processes, work type, machine data, material data etc are acquired and supplemented into knowledge base. Secondly, Adjusting information elements. Typical parts, typical operations, operation modules, fabricating parameters etc are reconfigured by adding and modifying new elements with basic information or deleting some information elements that will not be used any more. Thirdly, Reconfiguring knowledge elements. To selected knowledge types, check and modify each existing knowledge elements; construct new knowledge elements. For example, the influences of change of processes on the knowledge base lead to changes of the operation types, contents, modules and fabricating flow from bottom to up. New processes terms are added to the basic information base at first. Then new typical operations are added and the contents of existing operations are adjusted to adapt to the target enterprise. New operation modules are constructed based on operation modules and added to the flow table of knowledge base. Finally, a part

fabrication process flow design knowledge element is constructed by selecting the part and fabricating flow information elements.

3.2 Integrated application

The manufacturing engineering chain includes the design of fabricating order, tooling and manufacturing model and process parameter, numerical control code programming and other activities. Knowledge-based system for some manufacturing activity consists of knowledge base and knowledge handling logic. The integration application concerns about knowledge base, knowledge handling logic, manufacturing database and engineering design system. Process domain knowledge base contains new reused knowledge base built by reconfiguration and existing one, and it is the source of knowledge. Manufacturing database stores the engineering design information such as fabrication order, process parameters, die model and so on. Knowledge handling logic includes knowledge retrieving, inferring and updating. Engineering design system is performed by application systems and provides the environment of information display, editing and computing. The difficulty in integrating them is due to the differences of data format, development technology and DBMS etc. The integration relationship includes integration between engineering system and new reused knowledge handling logic, heterogeneous knowledge handling logic and existing knowledge base, knowledge handling logic and manufacturing database.

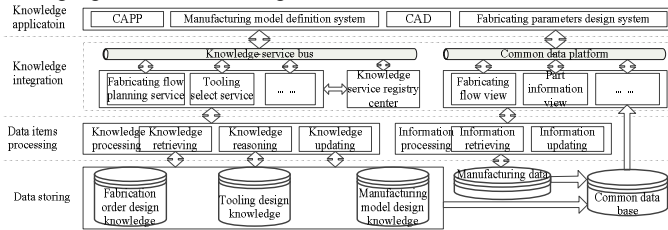


Figure 2: Loosely-coupled integration application of process domain knowledge

Tightly-coupled interfaces are usually used to integrate application system with knowledge base, and increase the dependence among the application systems and the cost of maintenance. It is not good for the system upgrade and extension. On the basis of influencing mode of integrated software and analyzing the integrated application process, a loosely-coupled mode of process knowledge integrated application was built based on process knowledge service bus and common data platform.

The framework of knowledge service bus based on service-oriented architecture is composed of knowledge service, knowledge service bus, service registry center and application systems. Knowledge retrieving, reasoning and updating are packaged as knowledge service and it is registered on the service bus. The knowledge service bus is used to connect and communicate with application systems. Application systems can inquiry and call the knowledge service. Service bus separates the application systems and knowledge service. It decreases the dependence of the integrated systems on each other and realizes loosely-coupled integration of application systems and knowledge-based system. That is to say, the flexibility of integration is increased.

The framework of this kind of integrated application is composed of knowledge bases, manufacturing database, common data platform and application systems. Information and knowledge sharing modes are specified in common data platform. The data views are built by taking knowledge bases and manufacturing databases as data sources. The inquiry users of shared data views are created on the common data platform, and application systems can get given shared data. In this mode, the data type and structure of the integrated knowledge bases and manufacturing databases need not to be modified, and only the data structure of the shared views is known by the integrated application systems, but not the original data tables and their relationships. Then a kind of loosely-coupled data and knowledge sharing mechanism is provided.

For example, the integration of fabrication order design knowledge base system is integrated with CAPP system in the target enterprise. In the target enterprise, the knowledge bases of machines, tooling and process files have been built and CAPP system is developed using ASP.NET. Part of the

reused knowledge base includes typical fabricating flow design knowledge, fabricating parameters, material data etc and the intelligent design tool is developed using J2EE. The integrated application scheme presented above is used to achieve the integration of reused knowledge base, existing resources knowledge base, CAPP system and intelligent design tool. Web services are used to package the tools of fabricating flow planning, tooling selecting, machine selecting etc as knowledge service and the knowledge services are released in service registry center. The common data platform is designed on the Oracle database and provides global data sharing views which include part information, fabrication order data and typical fabrication order design knowledge. CAPP system is integrated with the reused fabrication order design knowledge-base system flexibly. The part information and fabricating process result from the common data platform. Typical fabricating process planning knowledge and resources selecting knowledge services are utilized to complete the process planning rapidly. The FO design time is reduced 30%, the content quality is assured and the dependence on the designers' experience is decreased.

4 CONCLUSION

Intelligent manufacturing can enhance the enterprise's manufacturing abilities by providing flexibility, responsiveness and high-quality. Process domain knowledge reuse can therefore be possible from the technology point of view. However, process domain knowledge base is not easy from the beginning of creating a new knowledge base to integrating with the current computer-aided enabling systems because of its complexity. This obviously shows the necessity of process domain knowledge reuse across the enterprises to better the product manufacturing. The influencing mechanism of manufacturing scene change on process domain knowledge reuse is introduced in this paper. The mechanism is built based on the analysis of digital manufacturing scene and key factors influencing process domain knowledge reuse. The factors require the knowledge model utilization flexible to reconfigure and integrate with current CAX systems rapidly. The module-based knowledge model of process domain knowledge makes knowledge organize flexible and reconfigure rapid. Loosely-coupled integration application based on knowledge service bus and common data platform makes knowledge utilize flexible and digital manufacturing rapid.

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A VIBRATION MEASUREMENT SYSTEM FOR DEAF PEOPLE'S EMERGENCY APPARATUS

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ABSTRACT

A vibration measurement system for deaf people's emergency warning equipment is presented in this paper. Deaf alarm devices are among the most supportive products that help to alert deaf people in various emergency circumstances. Applicable British standards recommend that acceptable working parameters for such products are frequency: 25 to 150 Hz, enough vibration strength, intensity and stable performance against lifetime. This paper presents research that has been conducted to test and validate the performance of a variety of alerting devices using the proposed vibration measurement system. It introduces the laboratory arrangements, practical measurements carried out and its compliance with the British standards. The products investigated were the Mk I, Mk II Deaf Alerters, the Deafgard alerting device and the C-TEC 24V Pillow Pad. Measurements were taken using an ADXL335 accelerometer, to determine the vibration strength. Other parameters considered were temperature variation, efficiency and lifetime of the products.

Keywords: emergency, warning equipment, deaf alert.

1 INTRODUCTION

It is estimated that about 8.5 million people in the United Kingdom have some degree of hearing impairment and 250 million people worldwide have disabling hearing loss. Progress in the prevention of harm and death resulting from fire incident and disaster in the past few decades has not yet sufficiently addressed the needs of these people. The common fire safety device is the audible fire alarm, which saves thousands of lives each year. Unfortunately, these devices are of little benefit to deaf people, since the common method to alert deaf people is using vibration devices. These are devices that have a number of vibration elements and can be activated using wire and or wireless interface techniques. There are national and international standards that govern the performance of fire alarm equipment for hearing people. However, there are limited specific standards that can cover fire alarm equipment for deaf people. This disparity in fire safety provision is often caused by the failure to understand the needs of people who are deaf or have impaired hearing. One international Standard being increasingly adopted to control the quality and safety of products in the market is BS EN 14604:2005. It specifies the requirements, test methods and performance criteria for smoke alarms, for those devices that have a vibrating pillow pad, for Deaf and hard of hearing people. It is the main standard that currently addresses the performance of vibrating alert devices, even though it does not cover the performance of portable alerting devices like the Deaf Alerter.

This research work is aimed to validate the testing and measurement method developed and implemented by Deaf Alerter Plc., with a view to produce a vibration measurement standard that can be applied to all alarm systems for Deaf and hard of hearing people. It addresses the validation of vibration measurement versus temperature variation as well as over time. The research has passed through three main phases, first phase focused on integrating the new measurement systems

developed by Deaf Alerter Plc. into a mini housing unit with thermo autonomous temperature control system. This was to allow the measurement of various alert device performance versus temperature. The second phase concentrated on testing and measuring the devices performance parameters required by the British standard, for a number of alert devices. The final stage focused on comparing these measurements with the available British standards for fire alarm devices (David. Reeves, Brian. Kokoruwe, Jackie. Dobbins, Valerie. Newton, 2002, TriData Corporation, United States Fire Association, 2012) and provide the necessary recommendation for future use and utilisations.

2 VIBRATING ALERT DEVICES

There are a number of vibration fire alarm warning devices, for Deaf and hard of hearing people, available on the market. They can be classified into two types; the first type is fixed and has been designed to awaken sleeping end-users. This tends to be large and operates from a fixed location. The second one is normally small in size and portable. This is normally carried with the user during the daytime. These portable devices are activated by a wireless radio link, either from a fire alarm or smoke alarm. Four devices have been investigated during this research program and these are:

- Deafgard ([Http://WWW.Deafgard.Com](http://WWW.Deafgard.Com), 2011): Deafgard is a battery-powered stand-alone product, designed to awake people who are deaf or have hard of hearing from sleep when a nearby audible fire alarm is activated. The presence of continuous, high-volume, sound for more than 10 seconds causes the Deafgard to activate. The primary alerting method of this device is a vibrating pad, placed under the user's pillow or mattress.
- C-TEC BF363 24V Pillow Pad (<http://www.connevans.co.uk/store/viewProduct.do?id=1975157>, 2011): This device is designed to connect into a building's fire alarm system via a wall-plate and provides a warning when the fire alarm is activated. This product is typical of many similar devices supplied by fire alarm manufacturers. The vibrating pad is similar in size to the Deafgard device and is also designed to be placed under a pillow in order to alert a sleeping deaf person.
- Deaf Alerter Mk-I portable Alerter (<Http://WWW.Deaf-Alerter.Com>, 2011): The Mk-I Alerter is an adaptation of radio-pager, specifically to meet the needs of Deaf and hard of hearing people. It is battery powered, discreet and portable device. It is designed to be clipped to a belt or carried by the users. The end user is normally alerted by a combination of text display, flashing light, audible beep and vibration.
- Deaf Alerter Mk-II portable Alerter (<Http://WWW.Deaf-Alerter.Com>, 2011): The Mk-II Alerter is a replacement to the Mk-I Alerter. The new design incorporated several improvements, whilst retaining the form factor of the original product. Powered by a larger AA cell batter and it has smaller size and high strength vibration element.

3 EXPERIMENTS ARRANGEMENT, TEST, RESULTS AND DISCUSSIONS

Figure 1 (a) and (b) show the actual and block diagram of the test rig and experimental arrangement used in this investigation. It has been integrated with the necessary measurement units. The Deaf Alerter plc measurement unit was the core unit that has been used to measure the vibration of the above four alert systems. The devices tested were clamped to a SRBP platen, suspended from a welded steel frame by four 8SWG steel wires. This allowed virtually unrestricted vibration in the X and Y axes, with Z axis vibration being constrained by the stiffness of the suspension wires. It also enabled the measurement of a device's vibration performance in all three axes. An accelerometer module was fastened to the underside of the platen. Signal cables were routed from the module to a patch panel mounted at the foot of the A-frame.

The outputs from the ADXL335 accelerometer were fed directly into a 600MHz 4-beam sampling oscilloscope, from which measurements were taken directly using the screen cursor feature. ADXL335 is a small, low power, 3-axis accelerometer designed for cost-sensitive motion- and tilt-sensing applications. It is capable of measuring both the static acceleration due to gravity and dynamic acceleration due to motion, shock or vibration. It has an internal signal conditioning unit therefore the only external components required are a power supply decoupling capacitor and a bandwidth selection capacitor on each output. The frequency outputs ranges are from 0.5 Hz to 1600Hz in X and Y axes and 0.5 Hz to 550Hz for Z axis. The supply voltage was +3V and this generated output voltage for each axis of 300mV/g and at rated output of $\pm 3g$. The device is provided

with a sensor test feature, which enables verification of its performance (http://www.analog.com/static/imported-files/data_sheets/ADXL335.pdf).

The device is available from Sparkfun Electronics, mounted on a small printed circuit board with bandwidth capacitors fitted and all connections routed to a set of 0.1" pitch pads. Figure 2 (a) and (b) show the functional block diagram of ADXL335 module and actual measurement test rig suspension system integrated into the autonomous temperature control system. The actual measurement test arrangement comprised of a plastic enclosure, large enough to house the test rig. A domestic hair drier was used as a heating element. This was controlled by a Tempatron TC4800 to regulate the temperature inside the enclosure between 7 °C and 70 °C with approximately 2% accuracy.

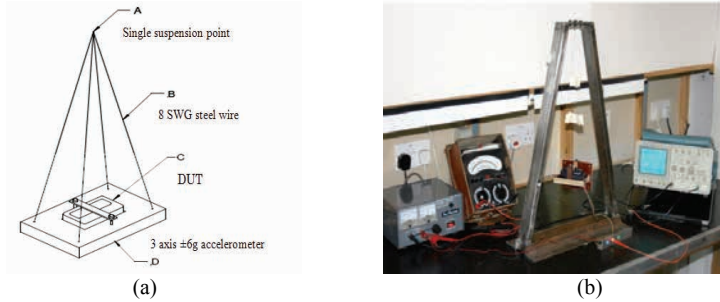


Figure 1: Deaf Alerter plc test rig (a) block diagram of the rig (b) the actual measurement Test rig Suspension System

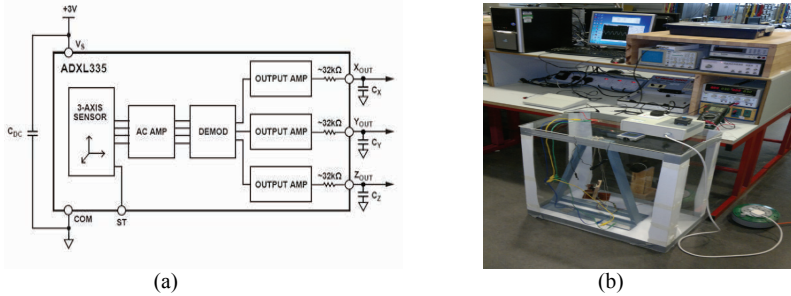


Figure 2: (a) ADXL335 Functional Block Diagram (b) Test Rig with a Temperature Control System integrated

Each device under test was fitted with a new battery and mounted securely on to the platen of the Deaf Alerter plc. test rig. A radio message was sent from a nearby test transmitter at an interval of 5 seconds. This caused the device to enter its 50% duty cycle vibration mode. The C-TEC device was activated by connection to a DC voltage source and the Deafgard unit was activated by depressing the 'Test' button on the control panel. Comprehensive tests were carried out at various degrees of ambient temperatures i.e. 6 °C, 7 °C, 25 °C, 40 °C, 50 °C and 65 °C. For each set of tests the peak value, repetition period of the X, Y and Z axis accelerometer output waveforms were recorded. The measurements taken included: Vibration strength, Performance versus temperature, Efficiency versus temperature, Efficiency versus operating time and Battery life time.

Figures 3 and 4 show the variation of operating frequency of the Mk I and Mk II Deaf Alerters versus the temperature. It can be seen that both devices operate most of the time within the frequency range of 25Hz to 150Hz. It also illustrate that both devices have an acceptable vibration strength and performance. These results ratify the suitability of both devices for deaf alert applications since they satisfy the BS EN 14604:2005 standards.

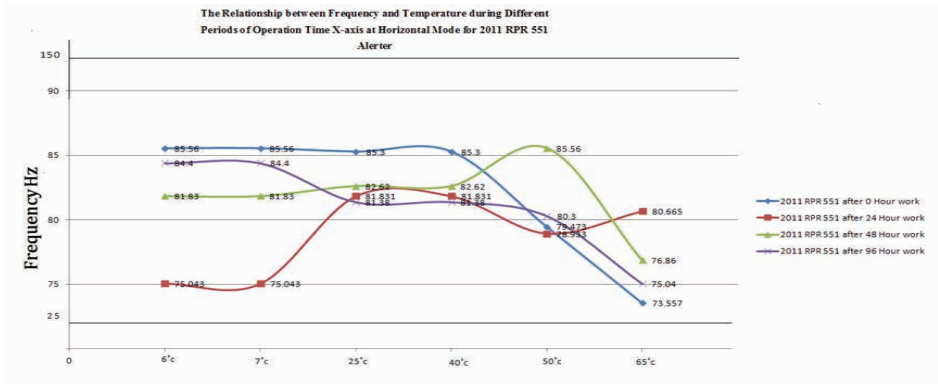


Figure 3: Frequency vs. Temperatures for Mk I Alerter performance in X-axis, Mounted Horizontally

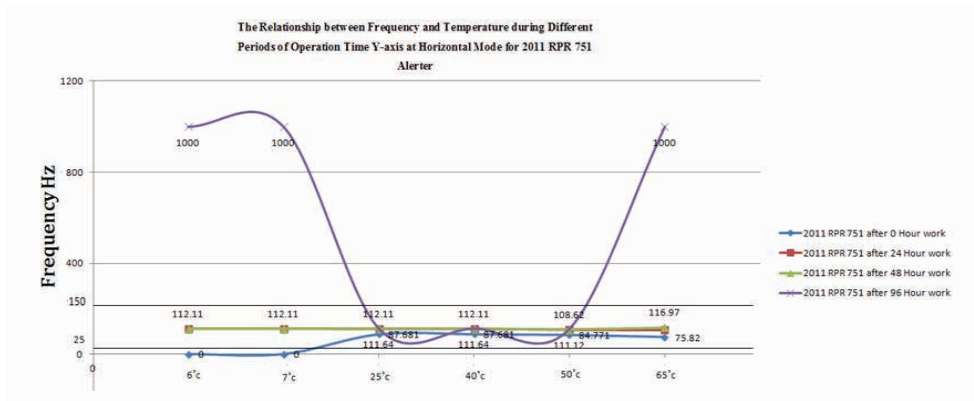


Figure 4: Frequency vs. Temperatures for Mk II Alerter performance in Y-axis, Mounted Horizontally

Figures 5 and 6 show the variation of operating frequency of the Deafgard and the frequency of C-TEC 24V Pad Pillow. It can be seen that the frequency of Deafgard and the frequency of C-TEC 24V Pad Pillow are hardly meeting the Standard's frequency range at certain temperature ranges and specific continuous working hours. However, it can be observed that they meet the standard at temperature range 25 to 50 °C degree and the performance dramatically changes after 48 hours of continuous working. This suggests that they are not fully working up to the standards at all the temperature ranges. However for such applications we are mainly focused in room temperature.

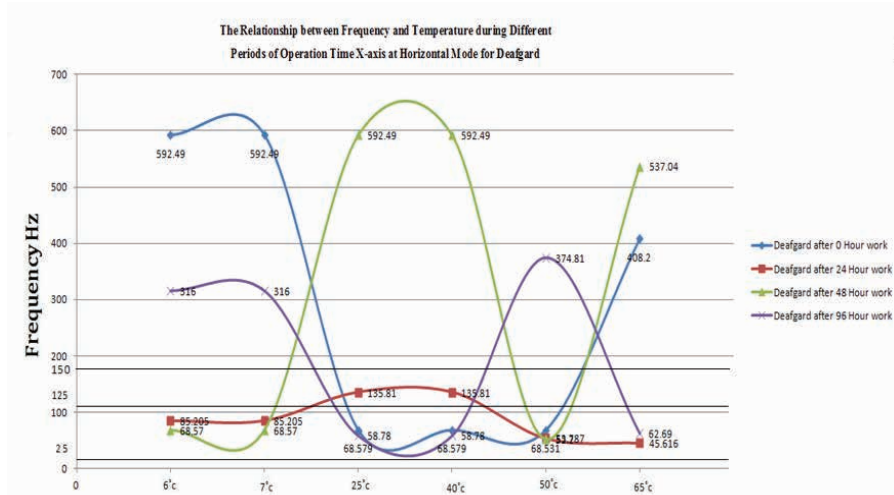


Figure 5: Frequency vs. Temperatures for Deafgard performance in X-axis, Mounted Horizontally

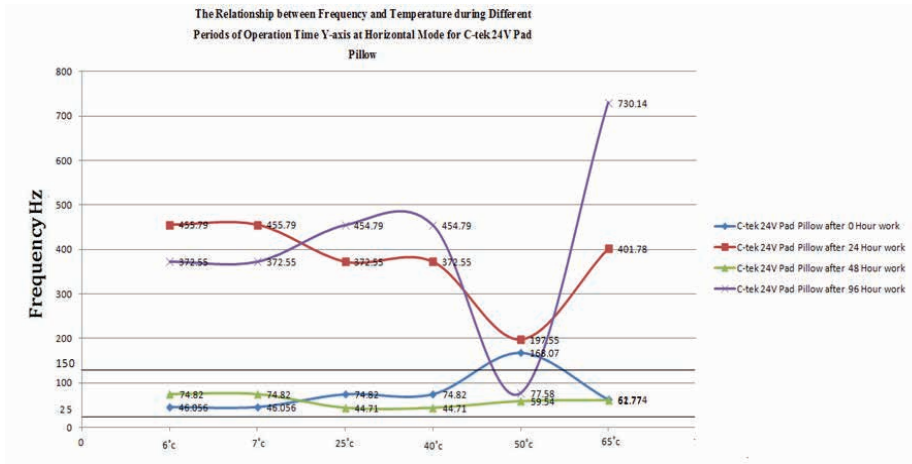


Figure 6: Frequency vs. Temperatures for C-TEC 24V Pillow Pad performance in Y-axis, Mounted Horizontally

4 CONCLUSIONS

A vibration measurement system for deaf people's emergency warning equipment is tested, validated and presented in this paper. This research work carried out showed the potential of the system to be used to measure the necessary parameters required by the British Standard, for a number of available deaf alerting products. The performance measurements of different alarm devices versus temperatures, in both horizontal and vertical orientations, in all 3 axes, were taken. The measurements were repeated at different durations of time. The measurements have been compared to the specifications from a British Standard to determine which of these devices follow the Standard and adopt its specifications.

It has been observed that the Mk I and the Mk II Alerter operate most of the time in frequency range of 25Hz to 150Hz. They also gave acceptable vibration strength versus different temperatures and different operating times. These provide enough evidence that both devices measurements meet the Standard requirement for such applications. However for Deafgard and the C-TEC 2V it has been observed that both devices meet the standard at temperature range 25⁰C to 50⁰C and the performance dramatically changes after 48 hours of continuous working. This suggests that they are not fully working up to the standards at all the temperature ranges. However for such applications we are mainly focused in room temperature.

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TOWARDS AN ONTOLOGY-BASED PLATFORM-INDEPENDENT FRAMEWORK FOR DEVELOPING KBE SYSTEMS IN THE AEROSPACE INDUSTRY

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ABSTRACT

Aerospace engineering is considered to be one of the most complex and advanced branches of engineering. The use of knowledge based engineering (KBE) technologies has played a major role in automating routine design activities in view of supporting the cost-effective and timely development of a product. However, technologies employed within KBE systems are usually platform-specific. The nature of these platform-specific models has significantly limited knowledge abstraction and reusability in KBE systems. This research paper presents a novel approach that illustrates the use of platform-independent knowledge models for the development of KBE systems in the aerospace industry. The use of semantic technologies through the definition of generic-purposed ontologies has been employed to support the notion of independent knowledge models that strengthens knowledge reusability in KBE systems. This approach has been validated qualitatively through experts' opinion and its benefit realised in the abstraction, reusability and maintainability of KBE systems.

Keywords: ontology, platform-independent, software engineering.

1 INTRODUCTION

The design and manufacturing of aircrafts usually requires careful understanding and trade-offs between technological advancements, design constraints, best practice knowledge, management and cost. Therefore, there is a significant emphasis on capturing, structuring and reusing product and process knowledge in the aerospace industry in order to maintain a competitive advantage. The use of knowledge based engineering (KBE) methods and technologies has played a major role in automating routine and mundane design activities in view of supporting the cost-effective and timely development of a product. Stokes (2001) defined the term KBE as *'the use of advanced software technologies to capture and re-use product and process knowledge in an integrated way'*. Developing these KBE systems usually requires considerable effort in capturing, formalising and codifying knowledge.

KBE systems covers a wide range of activities within the product lifecycle such as geometry creation, computer aided design (CAD), computer aided engineering (CAE), computer aided manufacturing (CAM), computer aided production planning (CAPP) and in-service and maintenance support. The design and implementation of these multidisciplinary KBE systems are usually platform-specific and domain-dependent. Due to the nature of specificity within KBE systems, knowledge reusability becomes an issue because the 'design' and 'implementation' of KBE systems are tied down to a specific technological platform. In software engineering, a platform-independent knowledge model is a model of a business or software system that is independent of the specific technological platform used to implement it. The notion of a platform-independent model is often used in the context of a model-driven architecture approach. The idea is to use a transformation language to transform a platform-independent model into a platform-specific model. In software engineering, the advantages of platform-independent models is separation of business/functionality logic from implementation logic. However, this approach is often not employed in the design and

development of KBE systems. For example, the design and development of a product component KBE system could be implemented in KF (Knowledge Fusion – automation language for KBE system) or in NX (Open API automation technology). Although these technologies possess powerful KBE functionalities that exploit advanced engineering knowledge, they are still considered as platform-specific models because its design and implementation logic is specific to a technological platform (i.e. specific programming language or operating system). Therefore, if there were to be a platform change, this will mean a complete re-write of the software system. This ad-hoc approach to developing KBE systems significantly limits abstraction and reusability as the engineering knowledge (i.e. key design parameters, design rules, mathematical expressions) within the KBE system is buried in code. The future generation of KBE systems will adopt a platform-independent approach so that the key design parameters and design rules for the KBE system is created independently of the KBE implementation as illustrated in Figure 1. Using a model transformation language will enable the transformation of platform-independent models into platform-specific models. This approach will significantly introduce a higher level of modularity and reusability in the design and development of KBE systems. Thus, reusing design and manufacturing knowledge from one KBE system to another becomes feasible.

In recent years, the engineering community (*i.e. researchers and industry experts*) has developed increased interest in the creation and maintenance of ontologies to support engineering activities. An ontology is a formal specification of a shared conceptualisation of domain of interest to a group of users. One of the most promising uses of ontologies as identified by Kitamura and Mizoguchi (2007) is that it enhances knowledge systematisation. This systematisation is mainly about the structure, abstraction and reusability of knowledge. Thus, this paper describes an approach that employs the use of ontologies as the basis of platform-independent knowledge models for designing and developing KBE systems in the aerospace sector.

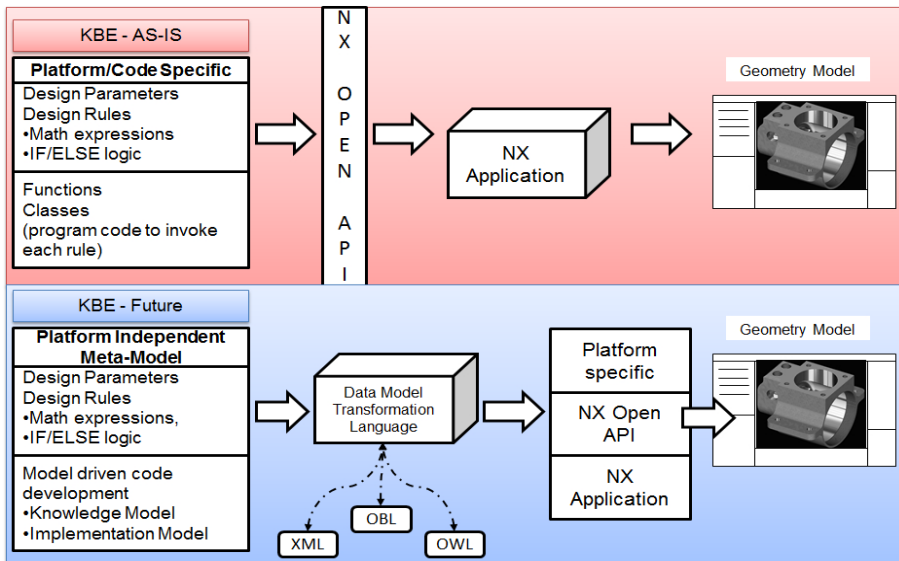


Figure 1: Platform Specific Model (PSM) vs. Platform Independent Model in the Aerospace Industry

2 RELATED WORK

Faigenbaum and McCorduck (1983) first established the definition of knowledge based engineering as an engineering discipline that involves the integration of knowledge into computer systems for the purpose of solving complex problems that normally require a high level of human expertise. Stokes

(2001) identified that the utilisation of knowledge based engineering (KBE) systems is used to automate manual and time-consuming design activities and knowledge representation within KBE systems goes beyond representing geometrical data and other factors should be considered. It has been established within the literature that 80% of design engineers activities is related to repetitive, routine and mundane tasks, while the remaining 20% on innovative tasks (Skarka 2007). However, applying KBE systems could significantly reduce repetitive tasks and allow design engineers to gear their focus towards innovative design activities.

The application of ontology based approaches in conjunction with semantic technologies within product design activities has become an interesting area within the literature. Chang et al (2008) proposes an ontology based support for product conceptual design. Conceptual design is perhaps the most intricate and difficult activity in the product development lifecycle because knowledge at this phase is usually inaccurate and incomplete. Due to the large amount of heterogeneous information that exist in product design (e.g. component, manufacturing process, assembly, etc), an ontology based approach was utilized to enhance the flexibility and reasoning of distinct and diverse product design information based on inference mechanisms. It was concluded that this approach has extensive capabilities beyond the traditional database approach which restricts the maintenance and extensibility of information. Furthermore, the use of ontologies has been applied and deployed in the product design industry to represent functional design knowledge (Kitamura and Mizoguchi 2007). However, it has been suggested that majority of the developed ontologies in industry have been applied to broad businesses and do not possess the same level of granularity and detail that is usually required for mechanical design (Kyoung-Yun et al 2006).

Gunendran and Young (2009) propose a design realisation system bridging the gap between product design and manufacturing. A product model, manufacturing model and library model was developed as a result and the use of the OCL (Object Constraint Language) was used to construct the production rules for a power transmission shaft using the commercial K-Pacs E2KS ontology knowledge base. Chungoora and Young (2010) further illustrate the potential of adopting more expressive formalisms in ontology languages to ensure the integrity of product design and manufacturing knowledge models. It has been established that several families of ontology knowledge based representation exists. Formalisms representations such as, Frame-based languages (F-Logic) (Wang et al. 2006), Description Based Logic languages (Baader et al. 2007) and Common Logic which is an ISO standard (ISO/IEC 24707 2007) altogether forms different level of expressiveness for ontological representation for product design information. However, it has been identified that there is a need for mathematical intensive approaches for the product design domain (due to the definition of engineering geometry) within these logic languages to ensure that the true and precise meaning of concepts within an ontology is fully expressed in order to prevent semantic loss between different systems (Das et al 2007).

The literature has highlighted that although there have been attempts made to use ontologies for developing KBE systems, there is lack of research studies focused on developing frameworks that will support the notion of ontology-based platform-independent knowledge models in KBE systems. There is no clear formalised link between ontology development and KBE systems.

3 ADOPTED RESEARCH METHODOLOGY

Due to the collaborative nature of the research study, it was essential that a research methodology satisfying both academia and industry was selected. A qualitative research approach and action research methodology has been adopted in order to jointly develop the framework with design and manufacturing engineers with several years of KBE industrial experience. The research commenced with a familiarisation stage in order to understand the KBE system domain within the aerospace industry. A total of 12 interviews were conducted with KBE experts. Participants included integrated design and manufacture engineers, knowledge based engineers, technical KBE leads with several years of aerospace industrial experience ranging from 10 – 25 years. Interviews commenced with other software engineering experts in the aerospace domain. It was established that the notion of a platform independent knowledge model is often employed in the software engineering discipline. However, this notion in KBE systems is not clear and there was a need to investigate this area and quantify its benefits. The interviews also clarified that some of the key KBE challenges faced in the

aerospace sector is the challenge of reusing KBE knowledge from one KBE system to the other due to the domain-specific and platform-specific approach often employed within KBE systems. A case study was conducted within the aerospace industry following the developed framework to develop an ontology-based KBE system for primitive geometric shapes as a proof of concept demonstrator.

4 DEVELOPMENT OF AN ONTOLOGY-BASED PLATFORM-INDEPENDENT FRAMEWORK FOR IMPLEMENTING KBE SYSTEMS

A framework for developing platform independent models using an ontology as the basis has been developed in the aerospace industry. The framework consists of four-phase as illustrated in Figure 2, namely (1) Capture KBE system knowledge (2) Ontology Model Construct of KBE system (3) Platform Independent Model (PIM) Technology Selection and Implementation (4) Integration of PIM KBE knowledge with CAD system. This framework forms a set of guidelines for KBE experts to employ in order to move from platform-specific KBE approach to platform-independent KBE approach. The first phase is to capture the knowledge required for the KBE system. This includes clearly identifying the purpose of the KBE system, defining 'use case' scenarios and functional and non-functional KBE system functionalities. A knowledge capture template sheet is recommended in order to capture specific knowledge required for the KBE system. The outcome of this phase should be a clear identification of the key design parameters and key design rules required for the KBE system. The second phase tackles the formalisation of the captured knowledge into an ontology for the KBE system. It is essential to identify a list of KBE concepts, KBE attributes and define concept to concept relationships as well as concept to attributes relationships. There is also a need to identify specific instances of the concepts identified. It is recommended to employ an object oriented paradigm (OOP) approach and model driven architecture (MDA) approach for this phase. It is also essential to graphically visualise and represent the ontology meta-model of the KBE system. One of the most important aspect of a KBE system is the rule-base. Therefore, there is a need to develop rules that are more maintainable and adaptable. A rule-based approach that provides such features are known as 'declarative rules' rather than the commonly used 'procedural rules'. In declarative programming, the rules are specified by defining what the program should accomplish rather than describing how to go about accomplishing it. Therefore, the logic of the computation is expressed without describing its control flow. The declarative approach to defining KBE rules are more adaptable and maintainable than the procedural approach and this can replace hard to maintain nested IF... THEN.. ELSE coding commonly adopted in KBE systems. The outcome of phase two is a formalised-ontology, clearly representing the KBE design parameters, rule-base (as a set of declarative rules) as ontology concepts and attributes.

The third phase of the framework focuses on selecting a 'fit for purpose' platform independent technology. Though, there are not many platform independent technologies that support KBE systems. However, there are capable ontology-based technologies that can be used for this purpose. It is essential to select a technology that supports declarative programming in order to model the KBE design rules using this approach. The KBE ontology model developed in the previous phases is implemented using the appropriate ontology-based technology. There might be a need to employ two ontology-based technologies in this phase. The first for modelling the KBE domain knowledge (i.e. design parameters as a set of concepts and attributes) and the other for modelling key design rules for the KBE system.

The fourth phase is to select an API for the CAD system. A suitable API will allow the integration of the platform-independent ontology knowledge-base with the KBE CAD system. The input and output of the ontology-knowledge based model is integrated with the KBE CAD system using a suitable API. It is important to note that the last phase might be time-consuming due to the need to understand the API. Platform independent ontology-based models might require more time to implement than the conventional platform-specific approach. However, the benefit of these platform independent models is realised in knowledge abstraction and reusability. This is of course essential for the long-term and future of KBE systems and for maintaining and preserving KBE knowledge. Important keywords used in the framework are described below: API – Application programming Interface, MDA – Model driven architecture and OOP – Object oriented paradigm.

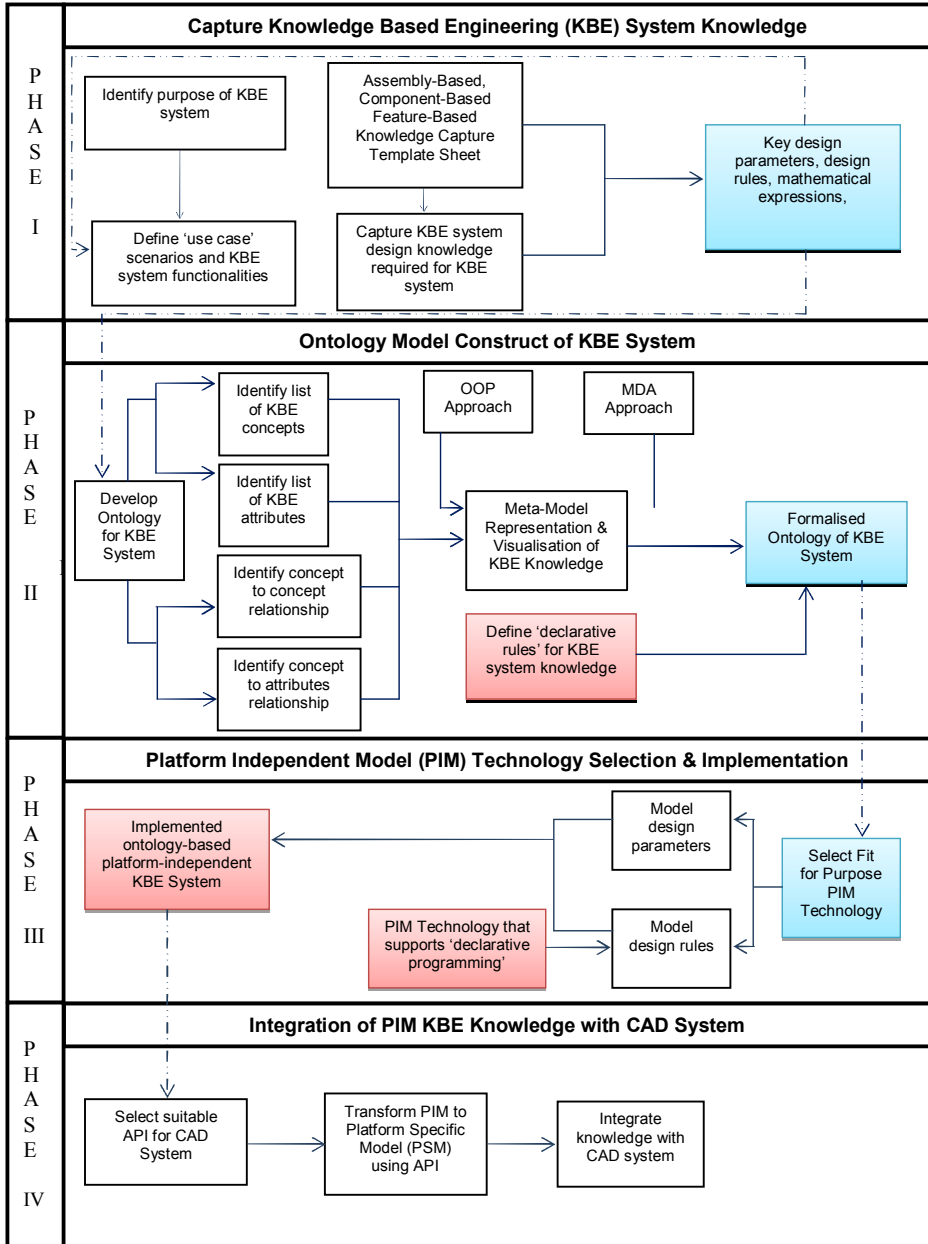


Figure 2: A framework for developing an ontology-based platform independent model for multidisciplinary KBE Systems

5 VALIDATION

The ontology-based, platform-independent model approach for developing KBE systems in the aerospace sector has been validated through experts opinion in a series of sessions. The experts agreed that the approach will significantly increase knowledge reusability and abstraction. However, due to the fact that there are not many technologies that supports this notion within KBE systems, it might be difficult to exploit full engineering knowledge and there might be limitations to the functionalities and capabilities of the use of available technologies for developing KBE systems. A case study was also conducted in the aerospace sector following the phases of the framework and showcasing a proof of concept demonstrator implementing an ontology based platform-independent model for primitive geometrical shapes in product design and development. It was identified that this approach should be employed in the future generation of KBE systems due to its benefits which are mainly high-level of reuse, reduction in development efforts and better management of KBE development complexity.

6 CONCLUSIONS

This research paper has introduced the need to employ ontology-based, platform independent models in the design and development of KBE systems. A novel approach has been defined that aims to bridge the link between ontologies, platform independent technologies, and KBE product design systems. Evidently, there is a benefit in employing this approach for the long-term development and maintenance of KBE systems. This approach has been validated through experts' opinion and case studies. However, there is a need to apply this approach on a larger scale (i.e. complex geometry components) to validate its scalability. There is also a need to raise the technology readiness level of the use of ontologies in the development of KBE systems as most of the application of this approach has been in demonstrator prototype. However, the framework developed will serve to support the notion of an ontology-based, platform-independent models for KBE systems.

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Uncertainty and Modelling

FACTORY MODELLING: DATA GUIDANCE FOR ANALYSING PRODUCTION, UTILITY AND BUILDING ARCHITECTURE SYSTEMS

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ABSTRACT

Work on energy and resource reduction in factories is dependent on the availability of data. Typically, available sources are incomplete or inappropriate for direct use and manipulation is required. Identifying new improvement opportunities through simulation across factory production, utility and building architecture domains requires analysis of model feasibility, particularly in terms of system data composition, input resolution and simulation result fidelity. This paper reviews literature on developing appropriate model data for assessing energy and material flows at factory level. Gaps are found in guidance for analysis and integration of resource-flows across system boundaries. The process for how data was prepared, input and iteratively developed alongside conceptual and simulation models is described. The case of a large-scale UK manufacturer is presented alongside discussions on challenges associated with factory level modelling, and the insights gained from understanding the effect of data clarity on system performance.

Keywords: Data Guidance, Factory Modelling, Resource efficiency.

1 INTRODUCTION

Global energy use has risen by 70% since 1971 and is set to continue its steady 2% increase over the coming decades, fuelled by economic expansion and global development (Clarke and Trinnaman, 2007). Along with increasing energy use comes consequent emissions of green house gasses and the depletion of finite natural reserves (Sorrell et al. 2010). Current rates of consumption are unsustainable, finite resources formed by the Earth over millions of years are being expeditiously exhausted by rising global population and associated increases in manufacturing to cater for our growing dependence on energy-intensive products (Al-Shemmeri, 2011 pp.13).

Energy consumption within industrial buildings equates to about a third of global energy use (Saygin et al., 2010). Around 70% is supplied by fossil fuel, which contributes 40% of CO₂ emissions (Brown et al., 2012). Analysis of current trends have incentivised legislative policies in sustainability, including the UK's Climate Change Act (CCA) (2008) and Carbon Reduction Commitment (CRC) Energy Efficiency scheme (2010). The CRC aims to reduce the use of energy intensive resources by specifying mandatory carbon allowances to industrial companies exceeding electricity consumption of 6,000MW/h, and applying financial penalties to those that overstep set limits (DECC, 2011).

Implementation of strategies concerned with the conservation of energy, materials and sustainable development have become increasingly important topics among governments, businesses, local communities and researchers (Pauli, 2010 pp.247). In factories, resource reduction activities have previously focused on point-solutions for discrete processes within manufacturing and building systems independently. However, new legalisation; such as the CCA and CRC, are motivating factories to establish greater resource efficiency across their functional boundaries. Increasingly, these efficiencies are being sought at a system level, encompassing energy, material and waste flows across production, utilities and building architecture domains. This paper discusses current modelling and data analysis approaches within literature and applies this guidance to the afore mentioned case study.

2 LITERATURE REVIEW

Systemic resource efficiency opportunities need to be found. These require detailed factory level analysis of resource consumption across domains and the introduction of inductive management methods to deal with data variability. Given the complexity and interconnectedness of resource flows at this scale, simulation has become an important ‘state of the art’ technology to aid design, analysis and testing of scenarios. The use of discrete event simulation can be extended to analyse energy, material and waste across domains. However, this gives rise to a number of data and modelling issues that are described below and classified in Table 1.

Model scope addresses the management within and between the production, utility and building-architecture domains, by using energy, material and waste flow data. This type of analysis could be used to identify interactions and determine potential variations in resource flows across system domains. Consecutively these analysis results could be used to determine improvement opportunities based on the tactical application of best practices (Smith & Ball, 2011). Modelling at this level provides contextualisation and control of system infrastructure (Herrmann, 2011), incorporating a realistic evaluation of energy and resource costs (European Commission, 2005), environmental impacts and technical performance. It allows for the derivation and selection of energy efficiency measures, beyond single machine improvement (Patterson, 1996). However, many large factories host a range of different system interactions, making data analysis and representative modelling of energy, material and waste at this level an elaborate process. Therefore, the model scope should account for preliminary qualitative analysis of data associated with these flows within a conceptual model (Figure 1). Definition of resource allocation and consumption across system domains allows for identification of when and where significant resource flows occur, as well as their duration, and whether they represent opportunities for improved resource efficiency (Oates et al., 2011).

Examining factories as an integration of production, utilities and building systems is necessary to consider the flow of all resources (Ball, 2013). When modelling complex interconnected systems a careful balance between feasibility, validity and utility is vital for achieving credible outputs. In order to achieve a representative model, definitions for both the scope of analysis and level of data are required. Existing frameworks for modelling and simulation provide a distinction between model scope and level of detail. The former identifies the boundary of the model, whereas the latter defines its depth (Robinson et al., 2011 pp.85). Simulation models can be conceived with four main component types: entities, active states, dead states and resources (Pidd, 2004). Mapping of these components within a conceptual model will inform key inclusion areas for further analysis and help refine the model scope. Once selected determining the level of analysis will require decisions to be taken about amount of data and detail to include for each component. The inclusion of these components within the conceptual model impacts all aspects of the study, in particular detailed data requirements, the speed at which the model can be developed, its validity, speed of experimentation and the confidence that is placed in simulation results (Robinson, 2011). Although effective conceptual modelling is a vital aspect of a simulation study it is probably the most difficult and least understood (Law, 1991). There is a paucity in literature for conceptual modelling applied to factory level, energy material and waste flow analysis.

Resource reduction in factories is dependent on the availability of data and sufficient automated or manual tools to enable collection. Typically collection is carried out by automated supervisory control and data acquisition (SCADA) and Energy Management Systems (EMS). However case experience has shown that available data can be incomplete or inappropriate for direct use and manipulation or modelling assumptions are required. Identifying new improvement opportunities requires clarity in the usability and fidelity of data being collected and analysed. This is particularly relevant in the experimentation stage of simulation when input granularity and quality, will have a direct effect on the ability to manipulate the model and provide valid outputs. The impacts of “big-data” gathered from current SCADA systems and manual data loggers on factories are twofold. The first is that volume data availability has increased but the usability of this data is sometimes questionable. Secondly, there is the increasing importance in using the appropriate level of data (resolution) to produce effective results. As a consequence of unclear data guidance and a lack resolution specifications for producing models, companies collect large volumes of data from loggers and SCADA systems, but the level and quality can be bi-polar. Either the depth of data is not detailed

enough across the scope of the system to provide a realistic representation, or the fidelity of the model created can become too-detailed, time consuming and unnecessary for producing the required simulation output. Additionally, even with the development of improved SCADA and EMS systems (Thomas et al., 2004) errors can still occur, leading to corrupt, rogue and unusable data. There are also techniques outlined to improve the performance these collection systems (Afkham et al., 2012). As an alternative, combining production data with machine consumption specifications (available from equipment manufacturers) allows usage assumptions to be made within the model (Nellore et al., 2001). Modelling assumptions may also need to be taken in the absence of data by using subjective methods such as snap-shot modelling. For this type of modelling to be effective action research, documenting all possible data is required. However, simulation outputs may lack objectivity and validity (Desa and Christer, 2001).

Data resolution characteristics (granularity and quality) are important in defining a models interoperability, experimental configurability and performance. Data granularity and quality are linked to analysis level decisions, which directly effect model fidelity and composability. Granularity can be defined as the subdivision (detail) of system components, whereas quality relates to the time-step intervals (depth) of measurement taken from selected subdivisions. At Factory level the integration of data from domain sub-systems can create modelling complexity and compatibility issues due to heterogeneous sub-system data resolutions. Combining these different model data types poses a variety of challenges depending on the system being modelled (Sarjoughian, 2006). Therefore, consideration and further guidance on composability; defined as the capability to select and assemble simulation components in various combinations within valid systems to satisfy specific user requirements (Petty and Weisel, 2003), is essential in developing representational factory models, with the ability to identify resource efficiencies.

Data accuracy is key to producing feasible and verifiable simulations. Identification of errors is dependent on the modellers ability to investigate the data and there sources. Analysis of system data (traces) can be carried out using range of static distribution methods (empirical, statistical, etc.) (Robinson, 2004 pp. 99). Mass and energy balance checking is another way to validate the accuracy of model data. This technique uses thermodynamic processes to define system energy and losses, providing a measure for efficiency of the resources transformations (Bakshi et al., 2011).

Table 1: Summary of issues identified in the literature for guidance on data and model development.

<i>Aspect</i>	<i>Challenges</i>	<i>Guidance</i>	<i>Source</i>
Model Scope	Establish boundaries	Define data within conceptual model	Oates et al. (2011)
	Resource Flows	Allocation across conceptual model	Hermann et al. (2012)
Analysis Level	Detailing components	Mapping entities, inform development areas	Robinson et al. (2011)
Data Collection	Automated	Analysis of SCADA and EMS data volumes	Afkham et al. (2012)
	Manual	Analysis of portable metering gathered data	Case experience
	Estimation	Model assumptions due to unavailable data	Pidd (1999)
	Documentation	OEM specification, collation of data sources	Nellore et al. (1999)
Data Resolution	Completeness	Modelling with a lack of data	Desa & Christer (2001)
	Model Composability	System granularity and integration across model	Sarjoughian (2006)
	Time steps	Data quality and normalising across model	Turner et al. (2011)
Data Accuracy	Errors & Cleansing	Logged data accuracy	Robinson (2004)
	Model Validity	verify model outputs with process experts	Case experience
	Mass Balance	Efficiency of resource transformations in model	Bakshi et al. (2011)

3 CASE APPLICATION

Resource flow data has been gathered from a large scale UK manufacturer and is presented in the form of a conceptual model (Figure 1). This model was developed in iterative manner alongside data capture. Challenges from Table 1 were used to inform conceptual model properties such as model scope, analysis level and system data collection, with an aim of determining specific focus areas for further analysis within a detailed simulation model. Refinement of model focus areas within the simulation software (Figure 2) encountered a number of data collection, resolution and accuracy challenges. All case application modelling results are discussed below against each aspect of Table 1.

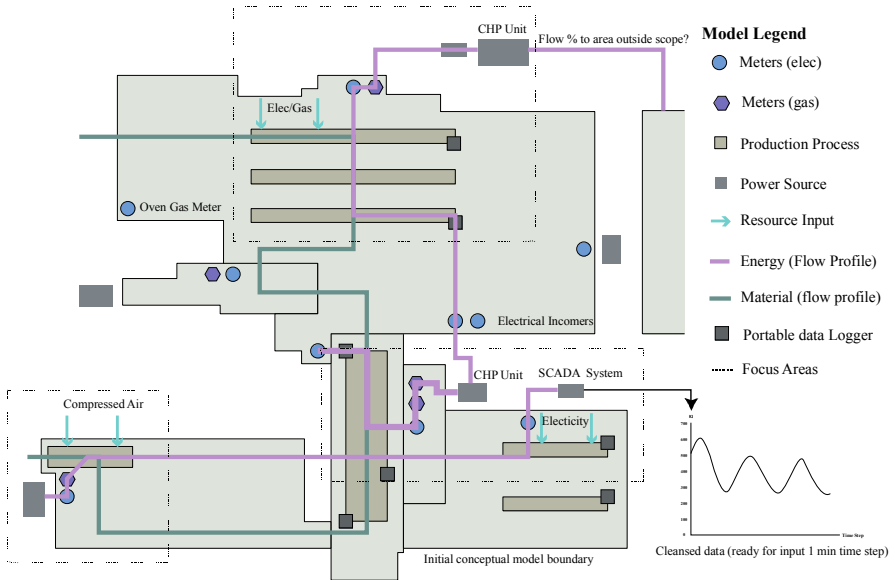


Figure 1: Conceptual model boundary, level components, qualitative resource flows and focus areas

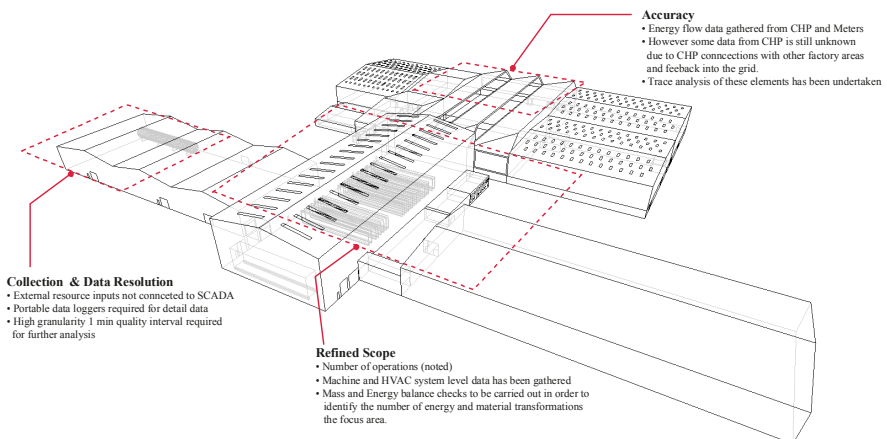


Figure 2. IES-VE model, showing refined model scope, data resolution and accuracy challenges

Model Scope: Initially defined by project goals, the conceptual model provided contextualisation allowing for the interactions of energy, material and waste flow data to be presented across domains. The model boundary along with definition of analysis level components was used to determine system areas for resource improvement opportunities, leading to a refined model scope within IES-VE suite.

Analysis Level: Collection of model components (e.g. processes, meter locations etc.) was based upon initial definition of model scope. Visual representation of flow allocation across the system was carried out within the conceptual model. The results yielded sufficient evidence of potential focus areas (detailed data collection) where high concentrations of energy and material resources were being consumed.

Data Collection: Based on analysis level and model refinement within IES-VE further detailed data was collected from on-site SCADA systems. Data accuracy checks were undertaken and some cleansing was required mainly due to human input (formulae) and sensor (missing detailed data) errors.

Data Resolution: Machine and HVAC system level data has been gathered at 1 minute intervals for focus areas. Although result output for this phase is still being undertaken, previous work undertaken (Turner et al., 2012) has shown that normalisation and data quality loss occurs at time-step interval over one minute. This shows that lower resolution data can detrimentally effect simulation feasibility.

Data Accuracy: currently a static trace analysis has been undertaken on detailed data. This revealed several pieces of rogue and missing data. Rogue data was cross checked by process experts and removed where necessary. Further empirical and statistical distributions of data are being undertaken within the model.

4 CONCLUSION AND FURTHER WORK

Data guidance from literature has aided development of the presented factory level models. The conceptual model was produced by establishing a model scope through goal setting and based upon accessible system data to contextualise the model components. Component data based upon analysis level guidance was used to generate energy and material flow maps across system boundaries. These flows were incorporated into the conceptual model in order to identify focus areas where high concentrations of energy and material resources were being consumed. Identification of these focus areas determined the refinement of model scope and the creation of a detailed simulation model. They also revealed where acquisition of detailed data was necessary, in order to create a representational model that would provide feasible resource efficiency opportunities. While developing the simulation model a number of data challenges occurred such as availability, resolution and composition of different system level data sets within the integrated model. Additionally, data accuracy has also affected the feasibility of the simulations. Further empirical and statistical trace tests to refine data within the model are required, in order to produce verifiable and valid output results. This research has identified guidance sources applicable for factory modelling and has developed an iterative approach for concurrent model building and data analysis. However, much work is still required in terms of developing a thorough modelling methodology that can be applied to factory level resource efficiency projects. Further work includes the development of a dynamic conceptual tool for representing interconnected components, systems and resource flow variability across the integrated production, utility and building architecture domains. It is also the researchers intention produce a set of guidelines outlining data typologies, showing how different data resolutions will directly affect simulation outputs and the application of resource efficiency tactics for factory level sustainability.

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A DIGITAL DEFINITION METHOD FOR MANUFACTURING MODEL OF AIRCRAFT INTEGRAL PANEL

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ABSTRACT

The manufacturing model of aircraft integral panel is presented based on the analysis of its structure and manufacturing process. The manufacturing model for each key process consists of model for processing and model for workpiece to bridge digital design and fabricating. Model for workpiece is used to express the target part information at the end of some operation. Model for processing is used to describe the intermediate state information, and it aims to attain but is different the workpiece because of process factors. The definition flow of the manufacturing model is given. The modeling approach of integral panel part blank from shot peen forming part model orienting to NC cutting is proposed and exemplified. It is analyzed that the approaches above can define the models accurately and totally to meet the needs of process planning , NC fabricating and inspecting.

Keywords: Digital definition, Manufacturing model, Aircraft integral panel.

1 INTRODUCTION

Aircraft integral panel has become the main force-bearing component of wing since the 1960's because of its high structure efficiency, smooth aerodynamic configuration, short process preparation cycle, less fabrication hours. Shot peen forming ranks as the one of the major processes for the manufacturing aircraft integral panels (Wang et al. 2002). It is well known that shot peening the surface of a metal sheet by small hard shot with sufficient kinetic energy can form a specific shape without need for forming die, and improve fatigue resistance of component significantly. It also has better adaptability to modern aircraft designs, for example, the capability to form tapered and sculptured integral structures, single and double curved shapes and virtually any size of parts (Wang et al. 2006).

The integral panel's manufacturing process starts at stock cutting and ends with finished part inspecting. The models that describe the information of intermediate parts at the different time in the fabrication process are crucial to forming the final shape. Nowadays, the component information needs to be described from a systematic view on the whole manufacturing process. First of all, the fabrication process consists of a sequence of working procedure, and the intermediate parts model must be defined accurately to drive the subsequent manufacturing activities, such as process parameters design, tooling design, NC Programming and so on. Furthermore, in order to take the three-dimensional (3D) model as the base in fabrication workshop, the geometric dimension and tolerance information, which was expressed in 2D drawing, needs to be defined, that is model-based

definition (Quintana et al. 2010). The 3D model of manufacturing information contains geometric and non-geometric information. The composition, organization and definition of discrete intermediate part information are the key to integral panel manufacturing.

A variety of frameworks for the product information modeling in manufacturing process have been used, including information modeling for product lifecycle (Sudarsan et al. 2005), manufacturing information model (Wang et al. 2006), multiple viewpoint model for assembly (Demoly et al. 2010). The information content represented in the model arises diversely, which mainly classified into geometric and non-geometric information. The geometric information represents the shape in the manufacturing process such as blank model (Wang et al. 2002), intermediate part information (Park 2006) and so on. Non-geometric information describes the GD&T (geometric dimension and tolerance) (Quintana et al. 2010), quality data (Tang et al. 2008) and other engineering features. Feature-based model is a typical method for organizing the part's information. There are both individual and shared information in models with different perspectives on product information, and redundant information across models should be avoided. From single view or local extent of geometry, material and quality, the composition and organization of manufacturing information have been given. However, to the special structure and its been forming process of aircraft integral panel, the structure of manufacturing model needs to be established further. Correspondingly, the definition process also needs to be taken into consideration from systematic view on the relation of multiple intermediate parts. The consistency across models should be ensured and the relations among the models should be built so that the related features are ensured to be updated when the design model are modified.

The current paper presents an alternate manufacturing model framework for aircraft integral panel that includes both geometric features and GD&T (Geometric Information and Tolerance) information so that the model can be used to digital manufacturing process. The content of the model are illustrated in detail and corresponding definition approach is presented as well.

2 MANUFACTURING MODEL OF INTEGRAL PANEL IN SHOT PEEN FORMING

The shape features of integral panel can be divided into base body and structure elements on it. Figure 1 illustrates the integral part's structure elements. The base body includes outer surface and inner surface modelled based on outer surface. The outer surface, as theoretical surface of aircraft, is the basis of integral panel design, which is classified into single curvature (ruled surface integral panel), double curvature (saddle-shape or variable hyperbolic supercritical wing), and the combination of them. The inner surface is stretched based on outer surface and the thickness of integral panel is different at various points. To meet the requirement of assembly strength, edge of integral panel should be strengthened by thickening.

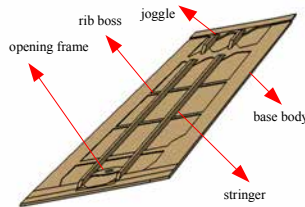


Figure 1: Example of integral panel structure

The structure elements, which is attached to integral panel base body, includes stringer, rib boss, joggle, opening frame, lug and so on. Stringer is often perpendicular to inner surface and reference of its modelling along the its axis on outer surface. In addition, the cross section of the stringer may be uniform and non-uniform. The lug can be added on the base body for assembly. Rib boss is modelled on the basis of outer surface and is used for strengthening structure, and often has equal thickness. Joggle is used for assembly and has constant deepness. Opening frame is used for the convenience of aircraft maintenance, and is a kind of combination of hole, groove, cover joggle and stiffener for improving structure strength and stiffness.

In digital manufacturing process, demand of manufacturing model is mainly original from the procedure of changing material shape and size. Orienting to the fabricating process, the manufacturing model is defined to bridge digital design and manufacturing on the basis of the part design model, which expresses the target shape. The fabricating process is composed of a sequence of working procedures, and consequently the manufacturing model is composed of several models of manufacturing state that expresses the feature on the different time in the process from the stock to the final part. The manufacturing model orienting to each key process is made up of two kinds of correlated model: model of workpiece and model for processing. The model of workpiece is used to express the target structure at the end of each working procedure and the model for processing is not same as the workpiece model of the process but for attaining it because of process factors.

The example part is fabricated by following the process chain. It is mainly composed of stock cutting, blank milling, material property inspecting, shot peen forming and shape inspecting. It is shown in Figure 2. NC milling of blank and shot peen forming of outer surface are two key working procedures. The blank of integral panel part is cut by NC milling from stock to flat outer surface with the structure elements and outer surface is formed by shot peen forming controlled by process parameters.

For the digital manufacturing of integral panel, the procedures of changing material shape and size include NC milling and shot peen forming. In order to support NC milling and shot peen forming, manufacturing model of blank and shot peen path should be defined. Blank model is used for generating NC code of milling and shot peen path model is used for designing the shot peen forming parameters.

Blank model is the direct data source for NC milling, and reflects shape and size of the structure after unfolding the design model of integral panel. While the plastic deformation is irreversible, there is not the only solution to the blank model.

Shot peening path model is critical to setting shot peen forming parameters of NC machine, which include peening flow, distance, angle etc. Shot peening path correlates with integral panel structure based on the lines of extreme curvature.

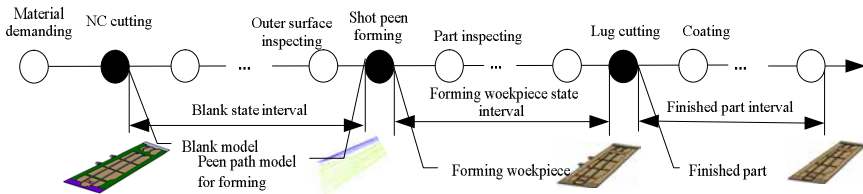


Figure 2: The process chain of integral panel fabrication and its manufacturing model

Manufacturing model is defined in three-dimensional CAD system, and each 3D model consists of geometric and non-geometric information. Geometric information describes the intermediate part shape, and non-geometric information describes the geometric dimension, tolerance, annotations (material feature, surface finishing etc.) and other features. The tolerances are defined in the models of blank and forming part for the inspecting working procedure after blank cutting and shot peen forming.

3 DEFINITION OF MANUFACTURING MODEL

The intermediate parts are correlated in the material flow of fabricating stock into final part, which is the basis of defining manufacturing state models. The order of defining manufacturing model is not from design model to blank model, that is to say it is not a reversible process of material flow, but decided by the dependent relations of the manufacturing state. The order of defining the manufacturing model of the example part is listed as follows:

- Defining the forming workpiece part by adding lugs on the design model;

- Defining the blank model by unfolding the forming workpiece;
- Defining the shot peening path on the blank model by computing the curvature of outer surface of forming workpiece.

The modeling flow of integral panel blank from design model orienting to NC milling process is shown in Figure 3. The blank part is transformed by the workpiece model for shot peened forming procedure. It is manifested by the changes of structure elements' shape and dimensions of forming workpiece model. The model definition of integral panel blank includes three steps: extracting geometric elements, calculating of unfolding geometric elements and blank modeling.

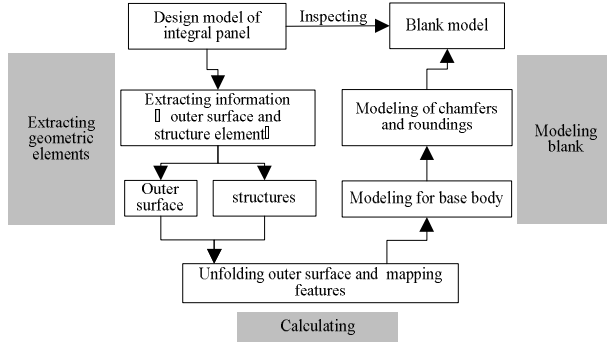


Figure 3: Definition flow of blank model



Figure 4: Extracting geometric elements

3.1 Extracting geometric elements

The geometric elements for unfolding are features that can be used to control the base body and other structure elements. As the deformation mainly occurs on the outer surface by shot peening, the structure elements attached to it are deformed at the same time, and the outer curved surface and the geometric elements, by which the structure elements are built, should be extracted. The extracted outer surface, points and lines of the example part are shown in Figure 4. When extracting geometric elements for unfolding, some rules should be followed.

- Pre-treat chamfers and rounding before extracting geometric elements;
- Ignore holes, grooves on outer surface;
- Extract the ultimate parent structural elements;
- Extract least elements for rebuilding structure elements;
- Do not extract a same geometric element twice.

3.2 Unfolding doubly curved surface into planar one

In the unfolding process, other extracted geometric elements are mapped onto unfolded planar surface panel by a mapping algorithm based on element deformation energy. The unfolding result is shown in Figure 5.

3.3 Modelling blank based on the unfolding result

Blank modelling is focused on rebuilding of inner surface of the base body and structure elements attached to it. In the modelling process, the inter surface of the base body is modelled by offsetting control points with a thickness value in direction of outer surface normal, based on the principle that the thickness of integral panel is invariable after unfolding outer surface. The structure elements are rebuilt by using the control lines and points to model sketch. Tolerances are defined by the requirements of inspection process after NC milling of blank. Blank model is shown in Figure 6.



Figure 5: The unfolded geometric features

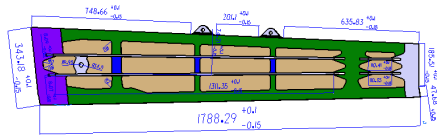


Figure 6: The blank model

4 CONCLUSION

Digital is the core of modern manufacturing technology development. For digital aircraft manufacturing, not only NC machine is used, but also the digital definition technology of product, process and resource in manufacturing needs developing. The manufacturing model is the key to integrate design information and material fabrication process. To support the digital manufacturing of integral panel, manufacturing model and its definition process is presented in this paper. Manufacturing model with model-based definition will change the current technology and make it possible the utilization of the digital information in fabrication process. With the contribution to some key technologies for its implementation, the tool of manufacturing model definition has been developed based on CATIA V5. Its applications, one of which is exemplified in the paper, have brought great benefits to the factories in terms of shortening production preparation cycle, manufacturing cost and operational efficiency.

ACKNOWLEDGMENTS

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SIMULATION OF HUMAN MOVEMENT AND BEHAVIOUR IN CROWDED SPACES USING GAMING SOFTWARE

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ABSTRACT

This paper discusses the development of human movement and behaviour simulation in crowded spaces as part of the AUNT-SUE (Accessibility and User Needs in Transport for Sustainable Urban Environments) research project. The research starts with applying a video observational method to understand human movement and behaviour in crowded spaces in the real world. Six hours of video were recorded at a multi-mode transportation system and almost 19,000 individual human movements and behaviours were analyzed. Six types of behaviour were derived from the three major movements of free, opposite and same direction. Six factors affecting human movement and behaviour were recognized from the video analysis. The DarkBASIC Professional gaming software was used to simulate the human movement and behaviour in the virtual world. The six factors affecting human movement and behaviour were considered as the parameters for the virtual humans. Case studies considering multi-mode transportation systems, bottleneck and non-bottleneck situations were applied to validate the prototype software system.

Keywords: AUNT-SUE, Video observation, Simulation, Gaming software

1 INTRODUCTION

Human movement and behaviour in the real world is an important input to develop human movement and behaviour simulation in the virtual world. In this research, a video observational method was developed to understand human movement and behaviour in real world. Six hours of video were recorded at a multi-mode transportation systems and almost 19,000 individual human movements and behaviours were analyzed. The steps taken in the video observational method are shown in Figure 1 and a detail discussion is provided in (Mohamaddan and Case, 2012)



Figure 1: The video observational method

The video observational method starts with the focus subject which is the individual human in crowded spaces with three focus movements of free, opposite and same direction. Six different types of behaviour were derived from the focus movements (Moving Through, Move-Stop-Move, Avoiding, Passing Through, Queuing and Competitive Behaviour). Based on the analysis conducted, six different factors (Personal Objective, Visual Perception, Speed of Movement, Personal Space, Crowd Density and Avoidance Angle or Distance) were recognized as affecting human movement and behaviour in crowded spaces. The steps taken for the video observations were enhanced and applied to develop the software design model for the virtual world simulation as shown in Figure 2.

Similar to a real world subject, the individual humans were selected as the focus entity in the software design. The factors affecting human movement and behaviour in the real world were designed as the parameters for each entity. The parameters refer to the command or source code for each entity in the virtual world before the program is executed. Different parameter values were set up for the entities based on information from the literature or assumptions made from observing different movement scenarios in the real world. Three types of movement (free, same and opposite direction) were selected for the entities in the virtual world. The movement of the entities in the virtual world was analyzed and compared with the movement in the real world in order to understand the advantages and limitations of the software. Selected case studies were conducted to evaluate the software.



Figure 2: The software design model

This paper discuss the strategy developed to simulate the human movement and behaviour in the virtual world using the DarkBASIC Professional gaming software and is based on a video observational method. The discussion includes the design of parameters and entities in the virtual world. An overview of selected case studies, namely the multi-mode transportation system, bottleneck and non-bottleneck layout design is also presented.

2 DESIGN OF PARAMETERS

In this research, the parameters represent the factors affecting human movement and behaviour observed in the real world. This section discusses the command or source code applied for each parameter in the virtual world. Some modification had been made to represent the parameters in the virtual world due to the limitations of the software. The parameters play important roles in developing different types of simulation that employ different movement scenarios in the real world.

2.1 Personal Objective

Personal Objective refers to the goals that humans have during movement. In the virtual world the Personal Objective parameter was represented by the command *Position Object* and *AI Entity Go to Position*. The *Position Object* command refers to the initial position or starting point for each entity in the virtual world before performing any movement. The *AI Entity Go to Position* command refers to the selected location or end point for the entities (shown in Figure 3). The *Position Object* and *AI Entity Go to Position* command was applied to develop the selected movements (free, same and opposite direction). Figure 3 shows the example of Same Direction Movement of the entities in the virtual world where the Personal Objective parameter is represented by the red path.

2.2 Visual Perception

Visual Perception refers to the visual region that humans have during movement. In the virtual world the Visual Perception parameter is represented by the view arc and the view range. The view arc is the angle at which the entities can see their surroundings. In the DarkBASIC the value of view arc ranges from 1 to 360 degrees and is represented by the *AI Set Entity View Arc* command. The view range is the distance where the entities can see from the current location and is represented by the *AI Set Entity View Range* command. The entities in the virtual world are able to see anything that appears within the view range and the view angle. Figure 3 shows the overview of the Visual Perception parameter that is represented by the coloured region in front of the entities.

2.3 Speed of Movement

Speed of Movement refers to the walking speed of humans during the movement. The Speed of Movement in the virtual world was represented by the *AI Set Entity Speed* command. This command sets the movement speed of the entity in DarkBASIC units per second (unit pixels). In DarkBASIC the units per second are dependent on the design of the entity. In this research, 5 pixels per second (DarkBASIC unit) was defined as equal to 1 cm per second in real world. An experiment was conducted previously (Cheong *et al.*, 2011) to measure the size of DarkBASIC units in real world measurements based on the design of the entity.

2.4 Personal Space

Personal Space refers to the invisible surrounding or territory around humans. The Personal Space in virtual world was represented by the *AI Set Radius* command. The command sets the global radius that is used by all entities in the virtual world. The command controls how much space is allowed between the edge of any obstacle and the waypoints that define movement around the entities. Since the entities use the waypoints to navigate around the virtual world, the entities will attempt to maintain at least the radius distance from all obstacles. An overview of the Personal Space parameter is shown in Figure 3.

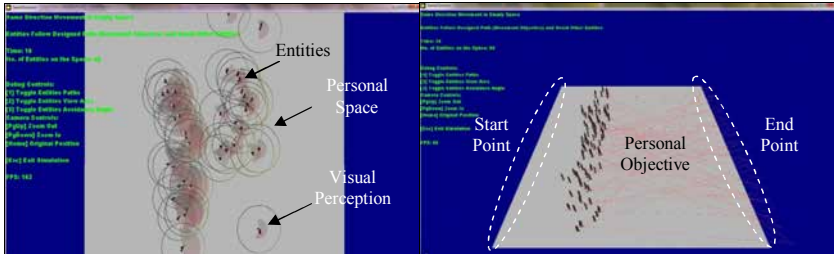


Figure 3: The personal objective, visual perception and personal space parameter

2.5 Crowd Density

Crowd Density is defined as the number of people per square meter for a standing and moving crowd. In the virtual world Crowd Density refers to the total number of entities per unit of floor area. The floor area for the simulation is designed accordingly due to the maximum number of 90 entities in order to ensure that a viable simulation can be conducted. The crowd density was designed with three scales namely low, medium and high crowds. Although the number of entities required for the simulation can be selected manually by the user, Table 1 below was applied as the guideline for the analysis.

Table 1: Type of crowd and the definition used for this research

Type of Crowd	Definition of the Crowd
Low Density	The movement of 30 entities within 600 unit pixels $\times$ 600 unit pixels (30 m $\times$ 30 m) area
Medium Density	The movement of 60 entities within 600 unit pixels $\times$ 600 unit pixels (30 m $\times$ 30 m) area
High Density	The movement of 90 entities within 600 unit pixels $\times$ 600 unit pixels (30 m $\times$ 30 m) area

2.6 Avoidance Angle or Distance

The Avoidance Angle or Distance refer to an action performed by humans to keep away from colliding with other objects or humans during the movement. In this research, the Avoidance Angle or Distance is totally based on the Dark AI effect from the movement as shown in Figure 4. The Avoidance Angle or Distance is represented by the green area in the picture. The Avoidance Angle or Distance is also affected by other parameters such as Visual Perception and Personal Space. When the floor area becomes more crowded (number of entities increased), the avoidance behaviour is observed to occur many times.

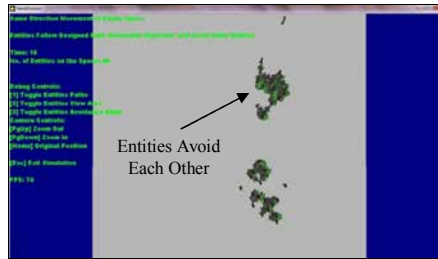


Figure 4: The avoidance angle or distance parameter

3 DESIGN OF ENTITIES

In the software design two subjects, the adult and the elderly person, were selected as the entities for virtual world simulation. Both entities was designed with the three dimensional appearance based on (Cheong *et al.*, 2011) to provide more realism for the simulation. Figure 5 shows the example of an elderly entity in the virtual world.

Table 2: The adult and elderly entity source codes in virtual world

Adult Entity	Elderly Entity
<i>AI Set Entity Speed I, 24</i>	<i>AI Set Entity Speed I, 16</i>
<i>AI Set Entity View Arc I, 160, 210</i>	<i>AI Set Entity View Arc I, 140, 190</i>
<i>AI Set Entity View Range I, 40</i>	<i>AI Set Entity View Range I, 20</i>
<i>Color Object I, RGB (0, 0, 255)</i>	<i>Color Object I, RGB (255, 0, 0)</i>

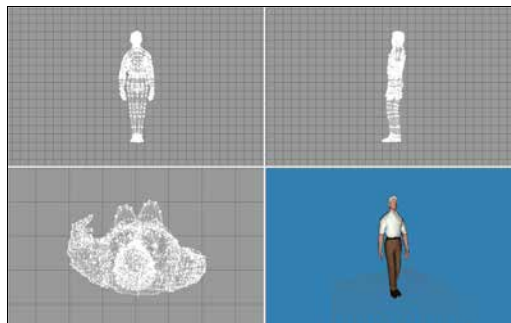


Figure 5: The elderly entity in 3D design

The source code for the adult and elderly entities in the virtual world is shown in Table 2. The values of the parameters were designed based on the literature (Sukhatme, 2001)(Teknomo, 2002) and assumptions made by the authors. The adult entity is set to be 24 unit pixels or 1.2 m/s speed of movement. The view arc is set to between 160 to 210 degrees with a view range of 40 unit pixels or 2 metres. The adult entity is identified by the blue colour. On the other hand, the elderly entity is set to have 16 unit pixels or 0.8 m/s speed of movement. The view arc is set to between 140 to 190 degrees with a view range of 20 unit pixels or 1 metre. Finally, the elderly entity is identified by the red colour.

4 THE CASE STUDIES IN THE VIRTUAL WORLD

The case study in the virtual world was focused on two types of design known as empty and building design. The empty design includes the simulation of movement by entities in free, same and opposite directions. The building design includes the simulation of a multi-mode transportation system, bottleneck and non-bottleneck designs. Each simulation was developed in a modular pattern where each simulation can be executed independently.

4.1 Empty Design

The empty design was used to simulate the movement of entities within the empty floor area as shown previously in Figure 3 (example of Same Direction Movement). The empty design simulation was conducted with two major objectives. Firstly, the empty design simulation is aimed to evaluate the parameters of the individual entities in the simulation. Different values of the parameters were selected to evaluate the parameters in order to understand how the parameters can affect the entities movement in the virtual world. The different parameter values can be used to represent different movement scenarios in the real world.

The second objective of the empty design simulation was to evaluate different sizes of crowd or crowd density. Although the number of entities can be selected manually in the range of 1 to 90 entities in the programming, the different size of crowd (low, medium and high density) is applied for the evaluation purposes. Table 2 shows the definition of low, medium and high density crowd. The results from the empty design are analyzed to understand human movement using gaming software and appropriate application were conducted to develop the software prototype.

4.2 Building Design

Building design simulation shows the movement of entities within three different types of building layout and is an example of an application developed from the understanding of entities movement in the empty design simulation. Three different types of building layout was selected namely the multi-mode transportation system, bottleneck and non-bottleneck layout design. The objective of the building design simulation was to determine suitable solutions for the design of crowded public spaces.

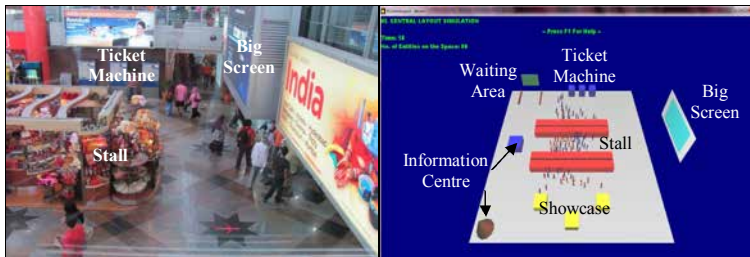


Figure 6: Multi-mode transportation system

The multi-mode transportation system was designed based on the Stesen Sentral Kuala Lumpur, the location for video observation analysis. Figure 6 shows the real world and virtual world layout design of the multi-mode transportation system that consists of different spaces or areas such as stalls, ticket machines, information centre, showcases and others. In the real world, the layout was designed to make the area more accessible and to be convenient for the users. However, the spaces might become obstacles for the users when the crowd density is increased. In this research, the layout of the transportation system is designed in the virtual world and applied to evaluate and predict the effect of different layout designs on the movement of entities in the crowd. Different layouts and obstacles were designed and the results compared.

Besides the design of multi-mode transportation systems, the building design simulation also focuses on the design of bottleneck and non-bottleneck layouts. The objective is to understand how the bottleneck and non-bottleneck layouts can affect the movement of entities in the crowd, especially during an evacuation process. Bottleneck design is defined as the phenomena where the design due to size of the door or pathway limits human movement. The bottleneck design can be found at many places in the building. Figure 7 shows an example of bottleneck and non-bottleneck layouts in the virtual world. The simulation shows the entities moving towards the end point which is the exit door that is marked with a red dot.

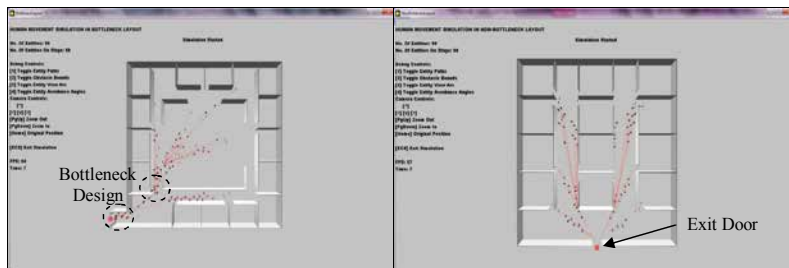


Figure 7: Bottleneck and non-bottleneck layout design

5 CONCLUSION

This paper has described the strategy developed to simulate human movement and behaviour in virtual world using the DarkBASIC Professional gaming software. The six factors affecting human movement and behaviour in the real world were applied as the parameters for each entity. Two subjects, an adult and an elderly person were selected as the entities for the virtual world simulation. The simulation was conducted firstly in an empty design in order to understand the advantages and limitations of the software. Applications using the building design included the multi-mode transportation system, bottleneck and non-bottleneck layouts were conducted to evaluate the software. For future work, analysis from the simulation will be carried out in order to further develop the software prototype.

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MODELLING LONG TERM DIGITAL PRESERVATION COSTS: A SCIENTIFIC DATA CASE STUDY

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ABSTRACT

In recent years there has been increasing UK Government pressure on publicly funded researchers to plan the preservation and ensure the accessibility of their data for the long term. A critical challenge in implementing a digital preservation strategy is the estimation of such a programme's cost. This paper presents a case study based on the cost estimation of preserving scientific data produced in the ISIS facility based at The Science and Technology Facilities Council (STFC) Rutherford Appleton Laboratory UK. The model for cost estimation for long term digital preservation is presented along with an outline of the development and validation activities undertaken as part of this project. The framework and methodology from this research provide an insight into the task of costing long term digital preservation processes, and can potentially be adapted to deliver benefits to other organisations.

Keywords: Digital Preservation, Curation, Cost Estimation, Whole Lifecycle Cost

1 INTRODUCTION

The long term preservation and accessibility of data is a pressing issue for publicly funded researchers. In light of this a question arises for the researcher and the funding agency: how is such preservation funded and managed in a sustainable way? It is only possible to address this question if there is a commonly understood basis on which the long-term preservation costs can be predicted.

In the case of scientific data there are several good reasons why having a digital preservation policy is essential. Data that is properly preserved can be used to validate analyses published of it and scientific conclusions drawn from it; data may be reused in meta-studies to discover effects which were not identifiable in one data set alone; it can be used to set parameters in, and test new theories, and it can be used to address issues which were not considered at the time of the original experimentation (for example, several data sets collected several hundred years ago have recently been used to model and predict climate change). Scientific data may be unique, unrepeatable and time dependent so it cannot be collected again; or the experiments, from which data are collected, may be expensive to perform.

The Science and Technology Facilities Council (STFC) is one of Europe's largest multidisciplinary research organisations. STFC is a UK government body that supports a national and international community of more than 10,000 scientists. ISIS is a world-leading centre for research in the physical and life sciences at the Rutherford Appleton Laboratory near Oxford in the UK. ISIS is effectively a large microscope, which uses neutrons and muons instead of light, to determine the properties of materials at the scale of atoms, without harming them. ISIS operates about 30 different instruments, at any time, which provide different details of the structure of a material. Hundreds of experiments are performed annually at ISIS by visiting researchers from around the world, in diverse science areas in-

cluding physics, chemistry, material engineering, earth sciences, biology and archaeology (STFC, 2012).

A critical challenge in implementing a digital preservation strategy is the estimation of such a programme's cost. This paper presents a case study based on the cost estimation of preserving scientific data produced in the ISIS facility and presents the methodology used for the costing and the selection of the chosen method of data preservation. Working with STFC the authors of this paper have been able to:

- Define the work breakdown structure (or work flow) for long-term digital preservation in ISIS
- Identify the cost drivers for the ISIS facility data preservation
- Provide estimates for five preservation scenarios developed by the STFC e-Science research team through three different activities (pre-archive, archive and access)

2 RELATED RESEARCH

Although cost modelling for the long term preservation of data from facilities such as ISIS has not been studied before, studies in several areas associated with cost modelling for long-term digital preservation are relevant. These studies can be split between the categories of long-term digital preservation and cost estimation. There have been many authors who have attempted to precisely define Long-Term Digital Preservation (LTDP) (Lee et al., 2002; Borghoff, 2006). Factor et al. (2009) offers the following definition of LTDP as the set of “processes, strategies and tools used to store and access digital data for long periods of time during which technologies, format, hardware, software and technical communities are very likely to change.”

The “digital data” mentioned by Factor et al. (2009) includes both the contents of the digital document and its metadata, which is the information describing the digital document (Borghoff, 2006). LTDP also aims to ensure the usability, the authenticity, the discoverability and the accessibility of the data (Lee et al., 2002). The definition provided by Factor et al. (2009) implies that there are the risks involved in digital preservation. Breeding (2010) briefly describes these risks as the “vulnerabilities of digital content”; the risk of data corruption and inaccessibility.

Ensuring digital preservation is not only about copying digital information; information must also be accessible for future processing (Lee et al., 2002). However, the main challenge is to interpret the digital document format (Borghoff, 2006) by producing an identical effect to that achieved on the original system. To answer this challenge, Lee et al. (2002) and Borghoff (2006) classify the LTDP techniques into two different technical approaches:

- The preservation of the original technological environment suitable for restoring the document in its original format,
- The continual transformation into the newest format while preserving the original “look and feel”

Table 1: Preservation Techniques: Advantages and limitations

Techniques	Key advantages	Limitations
Technology preservation	Ideal for short-term preservation: the authenticity cannot be better	Space, cost and durability of the devices
Technology emulation	Does not imply to save ageing original hardware and software but still keep authenticity	Requires precise, detailed and complex-to-create specifications and increases the amount of data to be preserved
Information migration	Well-known and widely used by IT services (several methods and tools exist)	Reduces authenticity and increases complexity (different components require different migration activities)

Encapsulation	More flexible and consistent with the emulation and migration techniques	The way of how the strategy may be practically implement is not clear
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To standardise digital preservation methods and provide a set of common best practices, several organisations have published guidelines, including the Open Archival Information System (OAIS) Reference Model. The OAIS Reference Model considers the context of the archive, as illustrated in Figure 1: An archive aims to store documents, submitted by a producer and delivered to a consumer; these activities are supervised by a management service (CCSDS, 2002).

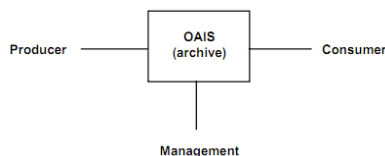


Figure 1: Environment model of an OAIS archive

The Life cycle Information For E-literature (LIFE) projects are a range of three consecutive projects based on existing long-term digital preservation cost modelling projects. They aim to deliver a cost model that can be used in the widest number of cases.

The Cost Model of Digital Preservation (CMDP) project is based on the OAIS Reference Model that provides a well-defined standardised breakdown of the relevant activities. It consists in the seven OAIS functional entities (Ingest, Data Management, Archival Storage, Access, Preservation Planning and Administration) as well as the three roles (Producer, Consumer and Management). CMDP project is based on the Activity-Based Costing technique.

3 RESEARCH METHODOLOGY

This paper aims to develop a cost model for the long-term digital preservation of data produced by the ISIS facility. In order to deliver this aim it has been necessary to employ a 3 phase methodology. The three main phases are: (i) understanding the context, (ii) data collection and analysis, (iii) model development and validation.

The first phase concentrated on examining the literature in long term preservation and cost estimation. The second phase concentrated on data collection and analysis in order to populate the cost model. This involved administering a questionnaire to more than 20 interviewees drawn from a range of roles within ISIS and STFC. The aim of the questionnaire was to establish the understanding of digital preservation held by the workforce of the two organisations and obtain the detailed responses required to accurately populate a cost model. Analysis of the data collected from the questionnaire was performed in the phase three. A cost model was then developed from the analysis and validated through two workshops held with experts drawn from industry.

4 PRESERVATION SCENARIOS FOR THE CASE STUDY

From the literature review (phase 1 in Figure 2) and by analysing the responses gained by the questionnaire (Phase 2 in Figure 2) it was clear that the encapsulation preservation technique was most appropriate for the scientific data at ISIS. A key feature of the encapsulation technique is that everything required to read a given data file must be archived with it. In the ISIS facility data is stored in the Nexus file format. The Nexus file is read by Mantid software, which can read, analyse and graphically visualise data inside the Nexus file.

4.1 Scenarios

In order to manage the risk of losing data (Conway et al., 2011) several preservation scenarios have been developed. The first preservation scenario, as shown in Figure 2, archives only the essential data.

Although this is sufficient for short-term preservation while the current Mantid application is still used by the community, there is a high risk of the data becoming unreadable by future applications. The second preservation scenario removes such risks by, among other elements, emulating the original operating system compatible with the original data file and application as illustrated in Figure 3 (Conway and Lambert, 2011). Between these two extremes there are another three options.

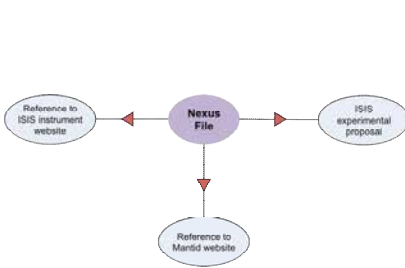


Figure 2: Scenario 1 – Basic Preservation

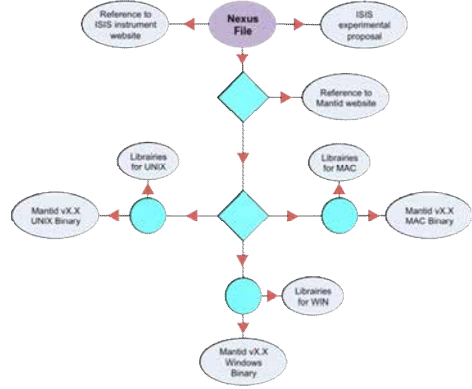


Figure 3: Scenario 2 – Extended Preservation

5 DEVELOPMENT OF THE COST MODEL

The development of the cost model was based on a combination of the analysis of the completed questionnaires and guidance from literature. The questionnaire was designed to be used in face-to-face meetings and to last from 30 minutes to one hour to fill, depending on the interviewee's field of expertise.

5.1 Cost Estimation Model

The aim of the cost model is to calculate the total preservation cost, at the end of Y-years preservation, when data has been accessed. This cost $C(Y)$ is so represented by Equation (1).

$$C(Y) = C_{PRE-ARCHIVE}(Y) + C_{ARCHIVE}(Y) + C_{ACCESS}(Y) \quad (1)$$

Sixteen cost elements were defined and can be divided into four categories, and so are calculated in four different ways:

- Human costs (related to people activity) or non-human costs (not related to people activity) respectively represented by Equations (2) and (3), and
- Recurring and non-recurring costs (in this case, Recurrence equals 1 in. Equations (2) and (3).

$$Human\ Cost = \frac{Annual\ Human\ Cost \times N \times Time\ needed}{Recurrence\ of\ the\ activity} \quad (1)$$

Where:

Annually Human Cost is made of the salary overvalued by 65% for the overheads.

N is either the number of people needed or the number of times the activity has to be done in one recurrence.

$$Non-human\ Cost = \frac{Numbers\ needed \times Buying\ Price}{Life\ Span\ or\ Recurrence} \quad (2)$$

5.2 Overall Cost Model Structure

The cost model development for this project consists of several different modules. The overall cost model structure is represented in Figure 4. It describes the connections between the different modules to deliver the cost estimations to the user.

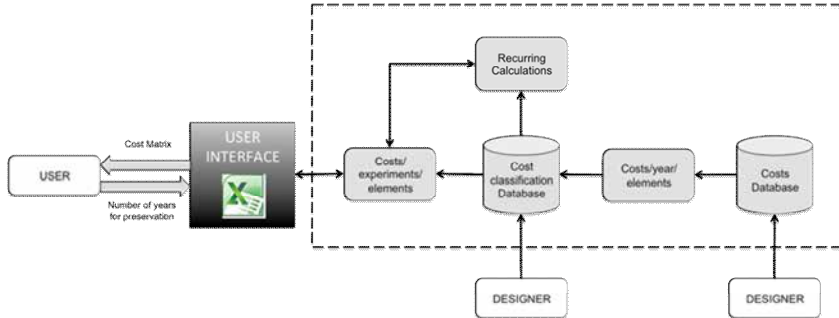


Figure 4: Cost Model Structure

6 VALIDATION

At present no ISIS scientific data long-term preservation cost estimation has been performed. Thus, the model was not validated through case study. However, two validation sessions were arranged with several experts in digital preservation and cost modelling. In the first validation session the developed cost model has been validated through a first expert judgment during a validation session. Four experts were invited to attend this session. The validation session lasted for around an hour. The general feedback provided on the cost model has been that it was meeting expectations of the experts. There is an appreciation of the level of detail in each cost element and the transparency of these costs. However, they noticed the lack of context around the scenarios and the assumptions inside the cost model: a user with a knowledge of what is digital preservation will have understood the phases (pre-archive, archive, access) but no one outside ISIS and e-Science will have understood the activities defined without previous knowledge of the project.

A second validation session was set up. More than 20 digital preservation experts from ISIS. The general feedback was that the cost model could provide a valuable insight into preservation costs at ISIS. An expert from the first validation session declared that: "The costs are following the trends I was expecting them to follow. Moreover, the range of costs seems to be realistic."

7 CONCLUSIONS

This research has delivered a model capable of estimating ISIS scientific data costs over the long-term. The model provides a matrix grouping of the three preservation phases costs (pre-archive, archive and access) through five preservation scenarios. It also compares these costs to the experiment rerun cost. In terms of cost modelling, long term digital preservation is a new area of research. This project will be used by STFC as a starting point for a larger project that they are partners in: Enabling kNowledge, Sustainability, Usability and Recovery for Economic Value (ENSURE), partly funded by the European Union. The ENSURE projects aims to provide new long-term digital preservation technologies. ENSURE will be based on three case studies from health care, clinical trials and finance and will focus on a number of issues, which have not been fully addressed by the literature up to this point.

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ADVANCED PERIODIC MAINTENANCE SCHEDULING METHODS FOR AIRCRAFT LIFECYCLE MANAGEMENT

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ABSTRACT

This paper reviews existing methods and techniques addressing the problem of maintenance support throughout the life cycle for high value manufacturing products such as aircrafts. As part of this doctorate research the analysis of current methods of maintenance scheduling was conducted. In order to contribute to a more comprehensive solution, an advanced approach (algorithm) of periodic maintenance is presented. The authors believe that this approach will reduce the cost of maintenance of high value manufacturing products. The algorithm based on constraint programming methods is briefly presented and the future research directions are discussed.

Keywords: Information systems, maintenance and repair of equipment, maintenance cost, periodic maintenance scheduling methods, methods of constraint satisfaction problem, domain ontology

1 INTRODUCTION

The competitiveness of the aircraft is influenced by a number of factors, including the operating system maintenance and repair of equipment. Maintenance and repair of equipment is an operation or a complex of operations intended to keep an item in the proper condition when used for intended purpose, on standby, for storage and transportation (GOST 18322-78 1978). British Standard Glossary of terms (3811:1993) defined maintenance as the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function. European Federation of National Maintenance Societies may be defined maintenance, repair, and operations as, "all actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required function. The actions include the combination of all technical and corresponding administrative, managerial, and supervision actions."

The increasing requirements for products quality and fluctuations in customer demand, as well as dynamic competitors impose significant requirements on the ability of manufacturers to provide customers with products in the required quantity, quality and for competitive price. From a purely industrial point of view, this means higher reliability of a company's technological capacities and their constant availability at the peak of their features. Thus the importance of maintenance effectiveness considerably increases, as well as the whole set of a company's asset management processes (Becker *et al.* 2006, Scheer 1994).

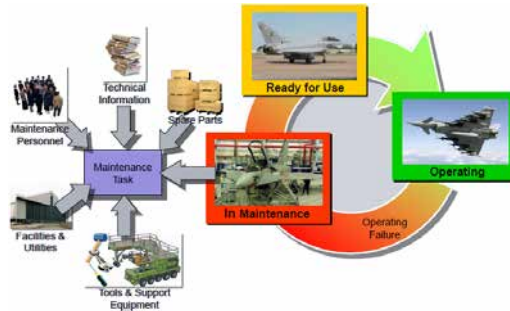


Figure 1: Maintenance, repair, and operations alignment to the service lifecycle. (c) Siemens AG, PLM Software Group

The main parameters that characterize the perfection of the maintenance system are the scope and frequency of maintenance work, which have a direct impact on operating costs and the intensity of the aircraft operation. It is obvious that the smaller the amount of work and the greater the frequency of their performance, the lower the operating costs and the stronger the aircraft operation. The share of the maintenance cost can vary from 10 to 50 percent of total operating costs, (Airline Maintenance Program Development Seminar, Fleet Maintenance Seminars, Boeing, Seattle, Washington, USA , 2008, Chapman 2006). The volume and frequency of maintenance affect The aircraft design features, the technical operation methods, regulatory and procedural requirements, the quality of work, operating parameters, environmental conditions and other factors influence on the scope and frequency of maintenance.

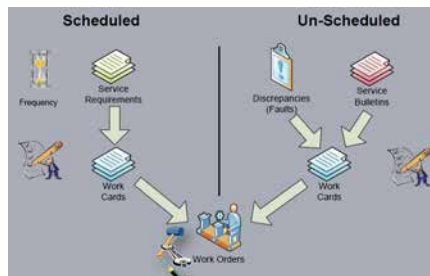


Figure 2: Scheduled and Un-Scheduled Maintenance. (c) Siemens AG, PLM Software Group

The scope and frequency of work are determined by the maintenance program. It should be noted that the requirements for the content of the maintenance program in Russia differ from those operating abroad. In the Russian Federation the maintenance program is a developer's document, common to the aircraft type, whereas the maintenance program abroad is a document developed by the operator for each individual aircraft taking into account the conditions and parameters of its operation and maintenance system adopted by the operator based on the minimum maintenance requirements specified in the process of type certification.

In this article methods of aircraft maintenance scheduling are considered.

2 MAINTENANCE SCHEDULING METHODS ANALYSIS

The objectives of an efficient airline maintenance program are:

- To ensure realization of the inherent safety and reliability levels of the equipment.
- To restore safety and reliability to their inherent levels when deterioration has occurred.

- To obtain the information necessary for design improvement of those items whose inherent reliability proves inadequate.
- To accomplish these goals at a minimum total cost, including maintenance costs and the costs of resulting failures.

These objectives recognize that maintenance programs, as such, cannot correct deficiencies in the inherent safety and reliability levels of the equipment. The maintenance program can only prevent deterioration of such inherent levels. If the inherent levels are found to be unsatisfactory, design modification is necessary to obtain improvement (ATA MSG-3 2007).

In the general statement in the presence of all the necessary initial information quantitative confirmation of maintenance program effectiveness is to provide a set of probabilistic aircraft safety performance, while minimizing maintenance cost (e.g., maintenance cost per flying hour). In this approach, the main difficulty is the quantitative confirmation of compliance with the aircraft requirements, which requires an adequate mathematical model allowing to assess the impact of maintenance on the aircraft safety and effectiveness.

Real alternative to the quantitative approach is the rational combination of quality engineering analysis of the choice of technical operation methods and the aircraft maintenance with a quantitative optimization of maintenance frequency on based on the mathematical model scheduled maintenance influence on the on-board systems reliability and safety. This allows to analyze the impact of possible system failures and their components on the aircraft flight safety, regularity and efficiency ("Applied Logistics" 2010).

A qualitative approach was proposed in the 70's by United Airlines and later became widely known as a guidance document on the development of a scheduled maintenance program - ATA MSG-3 (LII. MM Gromov, State Research Institute of Civil Aviation 2010). This document is recognized by the U.S. FAA, JAA and EASA European Union and is widely used by the aircraft developers and operators.

Practice shows that MSG-3 method has a number of drawbacks. MSG-3 principles have been refined and developed to Operator/Manufacturer Scheduled Maintenance Development (ATA MSG-3 2007), which engineers and service technicians can use to the create and maintain aircraft operation. MSG-3 method of maintenance scheduling describes the method for developing the scheduled maintenance program. Non-scheduled maintenance results from scheduled tasks, normal operation or data analysis.

Maintenance programs will be developed via use of a guided logic approach and will result in a task-oriented program. The logic's flow of analysis is failure-effect oriented. Items that, after analysis, have no scheduled task(s) specified, may be monitored by an operator's reliability program. The method for determining the maintenance program for systems/powerplant, including components and auxiliary power unit, uses a progressive logic diagram. This logic is the basis of an evaluation technique applied to each maintenance significant item (system, sub-system, module, component, accessory, unit, part, etc.), using the technical data available. Principally, the evaluations are based on the item's functional failures and failure causes. Before the actual MSG-3 logic can be applied to an item, the aircraft's significant systems and components must be identified. This process of identifying Maintenance Significant Items (MSI's) is a conservative process (using engineering judgment) based on the anticipated consequences of failure (ATA MSG-3 2007).

In the Russian Federation this task is carried out by specialists of "Applied Logistics" Scientific Research Centre of CALS-technologies. They proposed a "Method of maintenance frequency choosing on the basis of quantitative evaluation methods". Scheduled maintenance frequency is set so as to minimize the natural deterioration of inherent aircraft safety and reliability, its systems and components, preventing the level of aircraft airworthiness from exceeding the established standards. Scope of the aircraft scheduled maintenance is determined by a working group comprising representatives of airlines and a developer and is submitted for approval. In determining the aircraft maintenance work frequency standard modes of operation are considered: The average model flight, the average plaque ("Applied Logistics" 2010, Sudov *et al.* 2006).

Nowadays maintenance program scheduling is based on product passport data, organization standards, industry requirements, etc. In this case, lead time is rigidly fixed on the time axis by assigning scheduled maintenance intervals. Maintenance intervals are set cyclically. The work scope at every maintenance is formed depending on its type. Each maintenance type is provided with a list

of works given by the documentation to be executed as part of the maintenance. The main disadvantages of this method are: the inability to make changes to the maintenance program, lack of feedback from the servicing system, lack of data accumulation on the servicing system, low adaptive capacity.

Based on this analysis, the main goal of this research was defined as: to create a method and algorithm for improving scheduling of periodic maintenance actions (works) as universal maintenance procedures. This will greatly simplify the support of the whole system, expand the area of its use, and hopefully will reduce the maintenance cost of complex products (aircraft).

3 PROBLEM STATEMENT AND SOLUTION

Maintenance procedure is work scope $W_n = \{w_k\}$, where w_k is k -work, W_n is work scope, which is included in the maintenance P_n . Illustration of this fact you can see in the Figure 3.

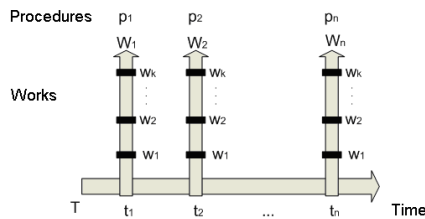


Figure 3: The task of maintenance scheduling.

The problem statement is the following: to define maintenance procedures work scope and time under which the selected criteria will take the extreme (minimum). For example, the selected criteria can be the following:

1. The maintenance total cost should seek to minimize: $S \rightarrow \min$, where S is the maintenance total cost;
2. Maximum procedure time of execution should seek to minimize: $R = \max(R_n) \rightarrow \min$, where R is maximum procedure time of execution.

The problem has to be solved taking into account special constraints. The special constraints can be the following:

1. Time period between the works must be less than or equal to the specified maximum time between the works;
2. If two works, determined by the compatibility matrix, are done in one maintenance procedure, their costs will be reduced by 20%.

A possible solution appear in the Figure 4.

N					1				
...			1					1	
7		1			1				
6									1
5				1					
4	1		1				1		
3						1			
2									1
1	1		1	1	1				
	1	2	3	4	5	6	7	...	K

Figure 4: A possible solution.

To achieve this goal we reduce the problem to the general problem of configuration design, which refers to the distribution of specific works among procedures.

There are two types of tasks on system configuration: selection and/or placement and hierarchy system. Our problem is the first type. Input: a set of elements/components, which is divided into subsets.

The essence of the constraint programming method is to describe a set of domain rules and constraints. Constraints may be presented in the form of equations, inequalities, logical expressions, etc.

Based on industry case studies and number of practical researches conducted with number of the aerospace companies we defined an advanced approach for improving the regular maintenance of complex, high value manufacturing products, described generally in number of stages:

- The functional decomposition of the work into a hierarchy of components and the composition of the work scope (maintenance/repair work domain ontology).
- Description of regularities determining the inclusion of this work in the periodic maintenance as constraints.
- Starting a mechanism to monitor the resulting complex maintenance work based on constraint satisfaction programming (CSP) (Rossi *et al.* 2006). The last stage consist of 3 sub-stages:

First sub-stage: satisfaction of the constraints that are associated with the known parameters of the components. Method NC-1 (Benhamou *et al.* 1997, Cleary 1987).

This algorithm allows to remove all the values that do not satisfy the unary constraints from all the domains of the problem variables.

Consistency in the nodes is achieved by viewing each item in each field and checking whether it satisfies the value of the unary constraints on that variable. All values that violate the unary constraints are removed from these domains.

Having completed the algorithm, the initial problem is reduced to the task, which is consistent in the nodes.

Second substage: the pairwise comparison of directory components, which is aimed at removing the components not compatible with each other. Method of pre-screening Forward Checking (Gent Ian, Bartak).

Using the method of Forward Checking the search space can be significantly reduced or completely resolved (Benhamou *et al.* 1997, Cleary 1987).

The basic idea of the method can be expressed as follows: if the set of inequalities becomes inconsistent while assigning the domain value to a variable, inconsistent values should be removed from the domains of the other variables. After that the search can be continued. In case the current domain is empty there is roll back to the previous level (Gent Ian). Domain is a set of components (works) from the directory.

The search should be started with the variables that have domains with the least number of values.

Third substage: the calculation and verification of compliance with the requirements of the design parameters. Backtracking method (Dechter *et al.* 2002).

Backtracking algorithm for solving constraint satisfaction problems (CSP) is compiled on the basis of a recursive depth-first search (Dechter *et al.* 2002, Semenov 2003).

This method involves the enumeration of all possible combinations by traversing the tree layout options with returns in case of the constraints are not satisfied, as shown in the Figure 5.

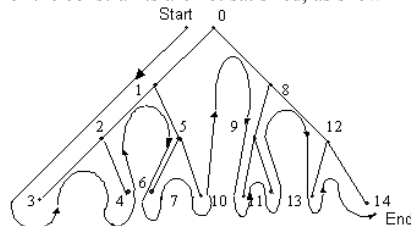


Figure 5: Backtracking.

The method allows to perform a full search of all the components combinations, and to find all possible solutions.

4 CONCLUSIONS AND FUTURE WORK

In this study, an analysis of existing methods of maintenance scheduling was presented. The key challenges and opportunities were defined. Advanced approach (algorithm) for periodic maintenance were described. The algorithm is based on constraint programming methods. The next step will be a creation of practical case studies for specific industry (aerospace industry) which will enable us to evaluate the effectiveness of the proposed framework. Also, cost reduction analysis (Taratoukhine *et al.* 2002, Becker *et al.* 2007) will be conducted to evaluate economic effectiveness of the proposed method. Finally, integration of the proposed solution to current ERP/EAM systems as joint co-innovation program between Bauman Moscow State Technical University/ERCIS Lab Russia and SAP will be considered.

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DESIGN AND DEVELOPMENT OF AN EMULATED HUMAN COGNITION USING NOVEL 3D NEURAL NETWORKS

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ABSTRACT

This paper describes the development of an Emulated Human Cognition (EHC) which is designed and based on a replicated human brain with a right- and a left- hand lobe, one a deductive side and the other a generic one. Right-hand lobe consists of a newly designed Artificial Neural Network (ANN) with a multi-hidden layer topology. Left-hand lobe is a newly designed 3-dimensional cellular neural network. The input variables presented to the EHC are immediately analysed for it to decide which lobe should be activated. The EHC, when fully developed, has almost an unlimited memory capacity and is capable of immediate recall of any data in its almost unlimited memory locations. EHC has been used in several applications where neural networks have been used to establish relationship between two or more sets of variables. In this paper the EHC has been used to forecast demand for a given product.

Keywords: forecasting, 3D neural networks, artificial neural networks, cellular neural network

1 INTRODUCTION

The research reported in this paper is a continuation of the Factories of the Future programme instigated in the early 1980s supported by the EU. The programme initially concerned aspects relating to high technology manufacturing with emphasis on automation cited in (Ziarati, 1989) and (Ziarati, 1989). The programme became more focused on system integration and development of information management systems in the 1990s (EUREKA (QMIS/IBIS, 1990-95) concentrating on the development of an integrated business information system (Ziarati and Khataee, 1994). Early in the 2000s, the Factories of the Future programme put a great deal of effort into wireless communication (Ozhusrev, 1992; Ziarati and Higginson, 1992), roadmap development (Yoji et al, 1999) and value stream mapping (Tapping et al, 2002), helping the manufacturing industry to be leaner and become more efficient. In the mid 2000s focus was diverted into a new concept now known as ‘Lean Optimal’ (Ziarati and Ziarati, 2009). The development of the lean optimal system led to the development of this Emulated Human Cognition (EHC). The earlier EHC is composed of an Artificial Neural Network (ANN) and a Cellular Neural Network (CNN). The CNN was later developed into a 3 dimensional network (3-DCNN). The recent work by Urkmez et al (Urkmez et al, 2007; Akdemir et al, 2007) also led to the development of multi-hidden layer ANNs. The following sections give a summary of the emulated human cognition and make references to the multi hidden layer ANN, and the new 3-DCNN. The EHC is then given the task of predicting the demand for a given type of ship. The predicted values are very good and proof that the EHC is capable of making the right decision

and has the capabilities to establish relationships between input and output data with an astonishing degree of accuracy and an acceptable level of reliability.

2 THE MAIN COMPONENTS OF THE EMULATED HUMAN COGNITION

The EHC is technically represented as a system composed of two parallel and distinct sides. One side is deductive and analytical and the other side is generic and descriptive. The deductive side is composed of a novel ANN and the generic side a novel CNN.

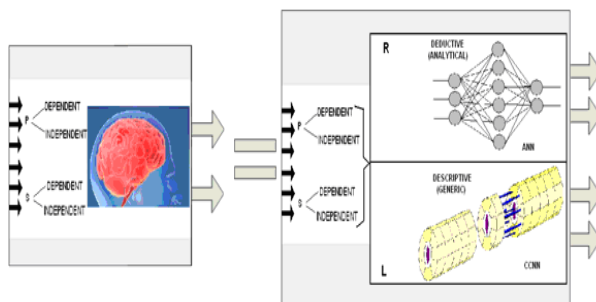


Figure 1. Description of Emulated Human Recognition

All four equations of motion were unified into one single expression and used in the modelling of all components when there is a flow of fluid (Ziarati, 1979). Using the same approach as (Ziarati, 1979) the system theory of $\Sigma = (U^r, X^n, Y^m, \alpha, \beta)$ was transformed into a family of $\Sigma_1 = (U^r, X^n, Y^m, A, B, C)$ for ANN applications. For CNN applications it was reduced to

$$\frac{dX}{dt} = -X + A * Y + B * U + I \quad (1)$$

2.1. Artificial Neural Network (ANN)

A good description of this type of ANN is given in (Ozhusrev et al, 2003). The ANN in 2007 was re-configured by adding additional hidden layers (Urkmez et al, 2007; Yucel et al, 2007) making these types of NN much more efficient and reliable. The ANN models reported in the latter references were based on the earlier work by Ziarati, Ucan and Bilgili who published several papers on the subject; a summary of their findings are given in (Urkmez e ak, 2007; Yucel et al, 2007; Akdemir et al, 2008; Urkmez et al, 2008).

In 1998 a new kind of artificial intelligence tool was proposed called Cellular Neural Networks (CNN) where the connections between neurons are restricted with their neighbours only (Chua and Yang, 1988). This type of NN is one of the most popularly used and is described in detail later in this paper. The work on the NN led to the development of Genetic Cellular Neural Networks (GCNN). A typical artificial model of a neuron is shown in Fig. 2.

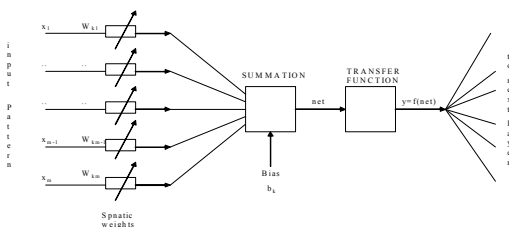


Figure 2. General Block Diagram of a Neuron

GCNN is a slight variation of the Cellular Neural Network which includes the application of Genetic Algorithms (Davis, 1991; Kozek et al, 1988). This network uses less stability parameters than Back Propagation-Artificial Neural Networks (BP-ANN) and hence should be better suited to fast changing scenarios experienced in real distribution systems. Details of GCNN for forecasting demand are provided by Ziarati et al (Ziarati et al, 2003).

A general CNN neighbourhood structure is shown in Fig. 3. The CNN structure is well suited for the computation of tabulated inter-related data. The CNN normalised differential state-equation can be described by matrix-convolution operators as follows:

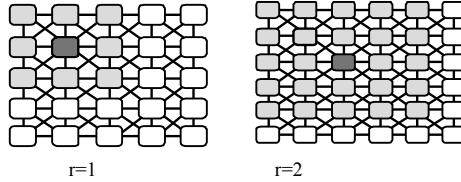


Figure 3. General Block Diagram of a CNN

$$\frac{dX}{dt} = -X + A * Y + B * U + I \quad (2)$$

where U, X, Y are input, state and output of an M x N matrix, while I is an offset vector. The feedback and feed-forward connections are represented by matrix A and B.

2. GENETIC ALGORITHM (GA)

Genetic Algorithm is a learning mechanism that abides by the rules of genetic science. The algorithm has been successfully applied in a number of cases such as image processing, geophysics, etc. (Davis, 1991; Kozek et al, 1988). It uses a binary coding system to search for optimum values of A, B, I. The underlying principles of GA were first published by Holland (Holland, 1962). The mathematical framework was developed in the 1960s and was presented in his pioneering book in 1975 (Holland, 1975). In optimisation applications, they have been used in many diverse fields such as function optimization, image processing, market research and product marketing, system identification and control and so forth. In machine learning, GA has been used to learn syntactically simple string IF-THEN rules in an arbitrary environment. A high-level description of GA was introduced by Davis. (Davis, 1991).

3. THREE DIMENSIONAL CELLULAR NEURAL NETWORKS

The development of this Network was started at Dogus University with support from Istanbul University. The Model shown in figure 3 was fully developed at TUDEV Institute of Maritime Studies (now Piri Reis University) in 2008 and tested in 2009. The model can be presented as a 3-dimensional table or a cylinder. In the model used here, CNN is composed of three-dimensional shaped cells. Some cells are placed at the inside of a cylinder. These are called inner cells. The other cells are placed around the cylinder and called the outer cells. In forecasting applications for instance, the outer cells will be used to process the independent variables (demand factors). The inner cells will be used to process the dependent variables - predicted parameter - i.e. demand for a product. Each horizontal ring represents values of variables at a given moment in time. 3-DCNN has the following dynamics for each inner cell $C_{mn}(k)$. For a given time n , the m^{th} independent variable is represented by $C_{m,n}$ and it is placed at the m^{th} outer cell of the n^{th} time segment. Its state equation is written as follows;

$$\frac{dx_{m,n}(k)}{dk} = -x_{m,n}(k) + A_{outercells}(m,1)y_{m,n-1}(k) + A_{outercells}(m,2)y_{m,n}(k) + B_{outercells}(m,1)u_{m,n-1}(k) + B_{outercells}(m,2)u_{m,n}(k) + I \quad (3)$$

For the inner cell of the segment n ;

$$\frac{dx_{p,n}(k)}{dk} = -x_{p,n}(k) + \sum_{r=0}^p A_{innercells}(r,1)y_{r,n-1}(k) + A_{innercells}(r,2)y_{r,n}(k) + \sum_{r=0}^p B_{innercells}(r,1)u_{r,n-1}(k) + B_{innercells}(r,2)u_{r,n}(k) + I \quad (4)$$

At the steady state condition; $y_{m,n} = f(x_{m,n})$

where $x_{m,n}$ is the state, $u_{m,n}$ is the input and $y_{m,n}$ is the output of the cell $C_{m,n}$. k is number of iteration, m, n are cell indexes, p is number of the outer cells for any ring. There are $p + 1$ cells in each horizontal ring since the index of the inner cell is zero. f is PWL activation function. A and B are the weight matrices including the weight coefficients between the corresponding cells. I : denotes the offset (bias) value of each cell in the network.

3-DCNN must be trained with sample data for obtaining the weight coefficients a_n, b_m and offset coefficient I as has been the case with CNN. In GA applications there are often two equations used. In the first equation, all outputs of the cells are compared to the desired values and the sum squared error is calculated with cost function according to following equation.

$$\cos t_s(a_n, b_m, I) = \sum_{m=1}^T \sum_{n=0}^p (y_{mn} - d_{mn})^2 \quad (5)$$

where y_{mn} is actual output d_{mn} is desired output of the cell C_{mn} , T is number of the segments, p is number of the outer cells and s is chromosome number. Fitness value of each chromosome is calculated as;

$$fitness_s(a_n, b_m, I) = \frac{1}{\cos t_s(a_n, b_m, I)} \quad (6)$$

4. EMULATED HUMAN COGNITION

In the experiment conducted the EHC was given a set of data and based on the data provided it can chose either the ANN or the 3-DCNN lobe. In this paper, only the result of one application in which EHC chose the 3-DCNN is presented. However, the full results are available, and if need be, will be presented at the Conference. In this application EHC was tested to see if it can forecast the Dead Weight Tonne, (DWT) for a particular type of a ship such as ‘Bulkers’ worldwide. As reported earlier the EHC opted for using the 3-DCNN. The aim of this application is to predict the DWT world fleet demand in total in the future by considering the historical data of DWT world fleet. In the training stage of 3DCNN, the genetic algorithm finds the optimum values of the matrices $A_{innercells}$, $A_{outercells}$, $B_{innercells}$, $B_{outercells}$ and I . There are 37 parameters to be optimized in this example. Each chromosome in genetic algorithm includes the binary codes of 37 parameters and each chromosome includes $296=37*8$ bits since each parameter has been coded with 8 bits. At the beginning of the genetic search 60 random chromosome were created. Then, the best chromosome was found at the 78^{th} generation. The templates of the best chromosome are;

$$\begin{aligned}
 A_{outercell} &= \begin{bmatrix} 0.531 & -0.325 \\ 0.006 & -0.012 \\ 0.312 & 0.287 \\ 0.319 & 0.281 \end{bmatrix} & A_{innercell} &= \begin{bmatrix} 0.431 & 0.281 \\ -0.087 & 0.606 \\ 0.687 & -0.131 \\ 0.469 & 0.562 \\ -0.381 & -0.519 \end{bmatrix} \\
 B_{outercell} &= \begin{bmatrix} 0.431 & 0.281 \\ -0.088 & 0.606 \\ 0.688 & -0.131 \\ 0.469 & 0.562 \end{bmatrix} & B_{innercell} &= \begin{bmatrix} -0.275 & -0.619 \\ 0.412 & 0.300 \\ -0.512 & -0.438 \\ 0.688 & -0.788 \\ -0.231 & 0.469 \end{bmatrix}
 \end{aligned}$$

Original and 3-DCNN output data values of this application are presented in Tables 1 and 2 respectively.

Table 1. Original data

	World Seaborne Total Dry Bulk	World Seaborne Total Bulk	World Seaborne Grand Total	World Fleet Total Bulk	World Fleet Grand Total
Years	Mil. Tones	Mil. Tones	Mil. Tones	Mil. DWT	Mil. DWT
1985	1461	2861	3631	499	590
1986	1415	2846	3636	478	568
1987	1332	2689	3635	471	564
1988	1410	2913	3907	469	563
1989	1595	3274	4173	475	572
1990	1598	3200	4164	489	588
1991	1625	3190	4201	502	604
1992	1596	3252	4345	514	619
1993	1616	3416	4554	520	627
1994	1673	3491	4658	528	637
1995	1784	3643	4877	529	640
1996	1816	3776	5121	548	708
1997	1910	3969	5432	559	725
1998	1897	3959	5443	570	742
1999	1894	3998	5566	573	750
2000	2040	4214	5913	586	767
2001	2096	4325	6022	601	787
2002	2170	4380	6209	607	800
2003	2291	4643	6553	618	819
2004	2469	4939	6954	634	843
2005	2564	5121	7258	670	890
2006	2703	5313	7615	715	950
2007	2790	5397	7852	758	1013

Table 2. 3-DCNN forecasting results

	World Seaborne Total Dry Bulk	World Seaborne Total Bulk	World Seaborne Grand Total	World Fleet Total Bulk	World Fleet Grand Total
Years					
1985	1460	2859	3631	499	589
1986	1416	2859	3628	479	570
1987	1334	2703	3625	473	564
1988	1409	2925	3893	471	564
1989	1592	3283	4162	477	573
1990	1599	3209	4156	491	589
1991	1625	3200	4192	504	605
1992	1597	3262	4337	515	619
1993	1616	3424	4545	521	628
1994	1673	3498	4650	529	639
1995	1782	3648	4867	530	642
1996	1815	3780	5111	549	708
1997	1908	3971	5422	560	725
1998	1897	3960	5440	571	742
1999	1894	3999	5561	573	750
2000	2037	4213	5904	587	766
2001	2094	4323	6019	601	787
2002	2168	4378	6203	607	800
2003	2288	4639	6547	618	819
2004	2465	4931	6948	634	843
2005	2561	5113	7255	669	889
2006	2699	5302	7611	714	949
2007	2787	5385	7852	756	1011
2008	2907	5558	8175	789	1058
2009	3013	5699	8479	825	1109
2010	3126	5846	8787	841	1142

5. CONCLUSIONS

It should be noted that the application was chosen at random from several available set of data (Urkmez e ak, 2007; Yucel et al, 2007; Akdemir et al, 2008; Urkmez et al, 2008). The comparison of the actual values for World Seaborne Tonnage and World Fleet DWT and the predicted values are remarkably good. This elucidates that the 3-DCNN is a good model and as part of the generic (descriptive) lobe of the EHC, it managed to make the right decision and use the 3-DCNN to carry out the millions of iteration to produce output values which are in good agreement with the actual values and better than the results reported in earlier papers. The merit of a 3-dimensional network is that it can be arranged to have a specific kind of input for each of its given ring. For example, one of the rings could be the primary values of the input and the next ring could be the secondary values. The same concept can be applied to dependent and independent values. The difference between CNN and 3-DCNN is that the rings forming the cylinder can be the time series for each given values of input and output values and hence 3-DCNN can be used in time series applications.

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A FRAMEWORK FOR IDENTIFYING UNCERTAINTIES IN LONG-TERM DIGITAL PRESERVATION

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ABSTRACT

With the current expansion in digital information comes an increasing need to preserve such assets. The ENSURE (Enabling kNowledge Sustainability, Usability and Recovery for Economic value) project, a research project under the European Community's Seventh Framework Programme, is the parent project to this research area and its aim is to conduct advanced research to address the challenges of Long Term Digital Preservation (LTDP) to ensure the successful preservation, availability and accessibility of preserved data in the future. Focusing on identifying uncertainties in the LTDP activities and their impact on cost and economic performance of digital preservation systems, this paper discusses a framework to identify uncertainties in LTDP for business sectors interested.

Keywords: Digital Preservation, Uncertainties, Risk, ENSURE

1 INTRODUCTION

Digital data is now dominating the information scene (Charles Beagrie Limited, 2010); most of the currently generated information and records are in digital format or end up being digitized. This is due to the existence of new technologies and the ease of handling these digital data forms by the users. In order to keep these vastly growing population of digital materials safe, useable, meaningful and accessible for a long period of time; preservation methods and techniques have been introduced and employed.

Enabling kNowledge Sustainability Usability and Recovery for Economic value (ENSURE) aims to provide a total long-term digital preservation solution for a new sector in the IT market. The businesses in healthcare, financial and clinical trials sectors are now interested to preserve their data, due to legal obligations and due to the increasing cost of data regeneration, especially in the clinical trials sector. Along with the new business sector, ENSURE is aiming to utilise cloud computing for storage and computing.

ENSURE aims to provide its customers from the three business sectors with a detailed cost and economic performance report. This will enable decision makers to select their long-term digital preservation requirements and have the highest quality preservation possible for the cheapest running cost and ensure ease of access to and security of data. ENSURE's cost model aims to tackle uncertainties and obsolescence issues that may arise. This is due to IT systems that are prone to failures and obsolescence. Failures and obsolescence issues will generate cost to mitigate, and a rigorous study is needed to estimate the impact on future cost due to these mitigation strategies. To have a real cost estimate,

that reflects the effect of uncertainties, ENSURE requires that the cost modelling development should include a thorough uncertainty study. This paper outlines a framework developed for identification of uncertainties in LTDP, which will feed afterwards into the cost model reflects cost impacts of these uncertainties.

2 UNCERTAINTY AND RISK

Uncertainty can be described as a state marked by the inability to specify an entity (outcome, event, or occurrence) with precision. It is the lack of certainty, a state of having little or no knowledge about the existing state, or future outcome. Uncertainties of different types influence the successful implementation of DP. It is important to bear in mind that uncertainty does not always imply loss or damage, they sometimes create opportunity for value creation. The rapid nature of change in current times (change in technology, change in economy, change in needs, change in markets etc.) has led to the need for better perception and understanding of the resulting uncertainties created by these changes. Uncertainties lead to risk, which can be negative, in which case there is eminent damage, loss or failure; or positive, in which case they are opportunities. A negative risk would be handled by mitigations, and a positive, by exploitation.

A fair amount of effort has gone into developing strategies to manage the influence of uncertainty. These efforts have encountered challenges due to the variable nature of uncertainty (Erkoyuncu, 2011). Prior research (Erkoyuncu, 2011) reveal that the nature of uncertainty is two-fold. It can be either aleatory or epistemic in nature. Epistemic uncertainty is uncertainty that is associated with limitations of insufficient data. They describe Epistemic Uncertainty as that whose influence can be reduced through an increase in knowledge, understanding, or (relevant) data; and Aleatory Uncertainty on the other hand as that uncertainty which remains unpredictable irrespective of available data.

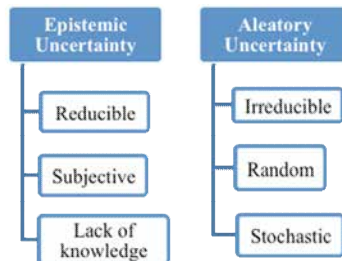


Figure 1: Natures of Uncertainty (Erkoyuncu, 2011)

The terms Uncertainty and Risk have often been used interchangeably; however, there is a blurred line of distinction. Erkoyuncu (2011) agree that the link between both concepts relates to uncertainty as the source of risk. They further point out that risk is a choice and not a fate, adding that undecided things are uncertain. Knight (2002) contributed to the study of uncertainty by describing it to be a complex from of risk. This tallies with other authors who share similar views about uncertainty which they describe as situations that are known only imprecisely or not known at all. They further state that a case of uncertainty can be better or worse than expected. Another more sophisticated definition which states that “Uncertainty is any deviation from the achievable ideal of completely deterministic knowledge of the relevant system.” Erkoyuncu’s extensive research in the area of uncertainty and risk gave rise to the following definitions: “Uncertainty is the stochastic behaviour of any physical phenomenon that causes the indefiniteness of outcomes meaning the expected and actual outcomes are never the same.” He considers risk to be a special case of uncertainty in which the outcomes of a specific event or events have a negative effect on the overall performance of a project. (Erkoyuncu, 2011). Figure 2 illustrates the relationship between concepts. It suggests that risk is embedded in uncertainty.



Figure 2: Uncertainty and Risk (Knight, 2002)

3 LONG-TERM DIGITAL PRESERVATION

The concept of digital preservation began as the term digital curation. The term was first used at the seminar Digital Curation: digital archives, libraries and e-science seminar. Both terminologies in terms of definition have one common theme, to make digital material available and usable in the distant future. The Digital Curation Centre (DCC) describes the term as being about “maintaining and adding value to, a trusted body of digital information for current and future use”. From Lord and Macdonald’s perspective, “This is a relatively new field, and terminologies are not yet stable...preservation is an aspect of archiving, and archiving is an activity needed for curation. All three are concerned with managing change over time.”. For the purpose of this work, the definition by Beagrie and Jones is adopted. “Digital preservation refers to the series of managed activities necessary to ensure continued access to digital materials for as long as necessary.” (Beagrie and Jones, 2001)

4 FRAMEWORK DEVELOPMENT

A framework within the context of this work can be defined as a structure providing guidance on a step-by-step approach for a goal. There is no doubt that more research has gone into risk handling as opposed to uncertainty. However, it has been successfully established in literature and this work that the handling of uncertainty is not solely about perceived threats, but also opportunity. Therefore, this framework is an effort to addressing the major uncertainties that impede successful LTDP, their corresponding risks, as well as mitigation approaches. The author anticipates that in implementing this framework, uncertainties can be addressed across sectors. It can also be used as a discussion and teaching tool. It has been developed with the aim of providing clarity and structure to the way uncertainty is discussed and handled.

4.1 Key Steps

1. The first and vital step in the development of an uncertainty framework is to actually understand what it means within your context of research. Therefore, upon review of definitions of uncertainty in general, the author has developed a working definition for uncertainty within the DP scenario.
2. The identification of uncertainties was achieved through a review of literature, company reports and interviews. Because of the stochastic and somewhat unpredictable nature of uncertainty, the author has narrowed research down to major uncertainties. Nevertheless, using this framework allows additional uncertainties to be considered. In other words, the framework is not limited to the presented uncertainties alone.
3. A step-by-step process was mapped out to guide the framework user on the identification and handling of uncertainties. Because uncertainty gives rise to risk, the uncertainty handling framework may be used as a precursor to the risk management process framework.
4. Simple tools were identified as useful for the identification of uncertain factors. Some of these tools include brainstorming, check listing etc.
5. The categorisation of major uncertainties was achieved based on descriptions in literature. An initial list was evaluated based on severity using questionnaire results and scenario analysis. This led to a final list.

Having successfully achieved all of the above, a framework was carefully put together (in a process flow format), by placing each objective in a manner that allows their combination to unfold meaningfully and make logical sense.

4.2 LTDP Uncertainties Taxonomy

Taxonomy serves as a map through the concepts of a subject. A taxonomic classification of uncertainties in LTDP has been identified as one of the objectives of this research work. In the taxonomic classification of uncertainties in LTDP, the author takes the perspective of the dual nature of uncertainty as being objective and subjective.

Objective uncertainty is associated with that uncertainty that is as a result of the stochastic characteristic of a factor. It is also known as Irreducible (or Aleatory) uncertainty, because in principle, it cannot be reduced through additional investigation. A characteristic of this uncertainty is though expert judgement may be useful in characterising it, it is not likely to be reduced by it.

Subjective uncertainty on the other hand is that which results from some form of knowledge deficiency or another. It is described in literature (Campos et al., 2007), as Reducible (or Epistemic) uncertainty, because it can be reduced by further empiric efforts. In principle, it is expected that this class of uncertainty can be reduced by sufficient study and expert judgement.

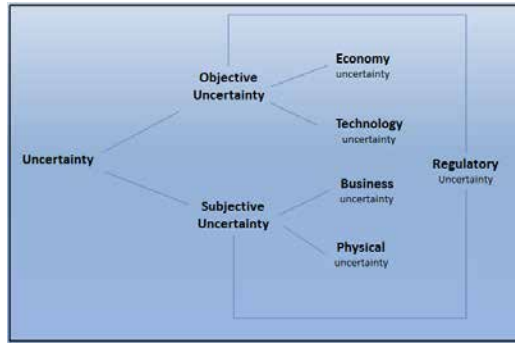


Figure 3: Taxonomy of Uncertainty in LTDP

4.3 Uncertainties Categories

Economic Uncertainty: Economic uncertainty implies the economy is unpredictable. There is a high likelihood of economic downturn, in which case there will most likely be a shortage of funds for LTDP activities; and also the possibility of an economic boom in which case; there will be available financial resources to effectively implement LTDP.

Technology Uncertainty: Technology is dynamic. Technology can be described as being in a constant state of evolution, hence the upgrades, updates, new versions, and the resulting obsolescence. Technology uncertainty is identified as a major category of because there is no guarantee that the preservation technologies used today to preserve data will still be the same ones used in few years to come.

Business Uncertainty: Every business is composed of tangible and intangible constituents. People, who could be stakeholders, employers, employees, vendors etc., are an example of tangible constituents. A businesses reputation is an example of an intangible constituent of a business. All these constituent generate a significant amount of uncertainty.

Physical Uncertainty: Physical uncertainties have to do with every element which can be seen, and whose impact is of a physical type. Physical uncertainties can be broken-down into subcategories of infrastructure, environment, storage etc.

Regulatory Uncertainty: As time changes, so does the economy, as the economy changes so, so do the regulations, laws, and policies.

4.4 Framework Implementation Tools

Figure 4 shows the full framework for identifying uncertainties in LTDP. The framework comprises the following stages:

Checklists: This is a preliminary technique used to provide a starting point to the identification of uncertainties. It guarantees that no known or common source of uncertainty to digital preservation is overlooked. It helps to ensure consistency and completeness in carrying handling uncertainties.

Brainstorming: To implement this tool, a group of knowledgeable stakeholders will come together in a formal process to list both known and new uncertain factors and risks about the prevailing context.

Interviews: This tool is introduced with the aim of identifying “concern-related” uncertainties and risks, and providing further information on risks potentially related to those identified by check-lists and brainstorming.

Structured “what-if” technique (SWIFT): This tool relies on expert knowledge for identifying and evaluating uncertainties, particularly taking into consideration the selection, preservation and dissemination stages of the preservation process, where change can be more influential, to identify potential risks arising from that change.

Failure Mode and Effect Analysis (FMEA): This tool is used to identify objective deviations and associated risks, potential causes, and consequences, regarding both the LTDP process and the digital repository itself, while making sure digital preservation’s objectives, needs, and requirements have not been neglected.

Reliability Centred Maintenance (RCM): This is used in order to identify preventive measures and policies that should be put in place to protect the digital repository, especially regarding the ingestion, preservation, and dissemination phases of the DP process, which are the ones which rely on the repository.

Human Risk Assessment (HRA): This is used to assess possible human impact on every stage of the preservation process.

Scenario Planning: Scenario planning may be used to envision potential futures and provide a mechanism for testing strategic assumptions in order to determine their robustness.

5 CONCLUSIONS

Preservation of these digital assets is riddled with uncertainties born from the influence of uncertain factors. The uncertainties then present risks of two main kinds – Opportunity and threats. Effective digital preservation is achieved when risks are addressed proactively, and the first step in identifying these risks is to handle the uncertainties which give rise to them. LTDP strategies must anticipate uncertainties, which is what this framework ensures, and thereby build in resilience to respond to any future events which are at the time unpredictable. It will most importantly ensure that the data preserved remains accessible and interpretable in the future when current technologies for servers, or operating systems, and applications may not be available.

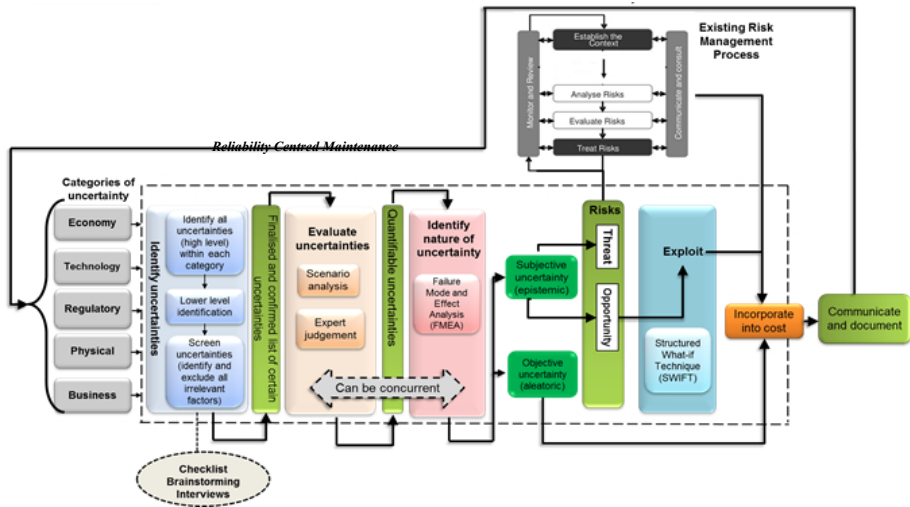


Figure 4: Uncertainties Identification Framework

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THE IMPLEMENTATION OF UNCERTAINTY EVALUATION MODEL IN MANUFACTURABILITY ANALYSIS SYSTEM FOR MINIATURE MACHINE TOOL

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ABSTRACT

The development of Manufacturability Analysis System for micro-machining domain (MicroMAS) is intended to address the need of the 4-axis Miniature Machine Tool (MMT) that require such system to assist the user in generating micro-component through manufacturability evaluation. One of the manufacturability aspects being assessed is the impacts from Uncertainty Evaluation Model (UEM) analysis that analyse the influence of the errors stemmed from the MMT construction on the geometrical accuracy of the machined micro-parts. The model has allowed a methodology for the errors in a custom-made MMT to be predicted and to further understand the origin of the errors on the machined micro-part. This paper reports on the implementation of UEM in the development of MicroMAS. Therefore, the results from uncertainty evaluation towards the MMT were integrated in the database which are interactively searched based on IF-THEN clauses in order to determine which rules satisfy the requirements expressed via inputs.

Keywords: manufacturability analysis system, uncertainty evaluation model, miniature machine tool.

1 INTRODUCTION

Manufacturability analysis systems (MASs) have been developed to enable the evaluation of easy to manufacture parts during the design stage, enabling the reduction of costs and time to market of the designed products. It is envisaged that MASs could enable the analysis of both manufacturability and functionality aspects such as dimensions/tolerances, surface finish, machining strategies related to material properties and part geometrical specifications; all considered at the early stages of product development with direct implications on the reduction of lead times of the product to the market (Bothroyd et al. 1994, Rao et al. 1999, Shukor et al. 2009).

MASs have been shown to be useful for macro-manufacturing processes but less attention or effort has been put for their development in the scope of micro-manufacturing (Shukor et al. 2009). In-house developed multi-axis Miniature Machine Tools (MMTs) are now becoming more popular with the demand for reduced energy consumption and workshop floor when machining small/medium batch size micro-components. As an example in watch manufacturing, due to the size of the miniature machines used, the amount of energy consumption may be reduced to approximately 30% of the conventional factory by the half-miniaturization of the production systems (Kawahara et al. 1997). The development of an in-house 4-axis MMT by the MCM Research Group at the University of Nottingham (Axinte et al. 2009) triggers a requirement for a system that can assist the user in generating micro-component using this custom-made machine. The development of MicroMAS for a custom-made 4-axis miniature machine tool (MMT) where various aspects (e.g. materials used, acceptable and suitable tolerances and dimensions) can be assessed to allow the design being compatible with the production needs that leads to improved quality of machined micro-product. In this study, MicroMAS can be defined as a system that assists the MMT user in generating micro-part based on the manufacturability analysis of a CAD model. The manufacturability aspects being considered are dimensions, tolerances, tool size, surface roughness,

features interactions, impact of uncertainty in machining the recognized primitive feature and material. At the same time, it also can boost the confidence in applicability of Micro-Engineering Technologies (MET) processes such as micro-milling, micro-drilling in producing micro-component.

Although MET is adapted from conventional macro-processes, the differences generated due to 'size effect' has made it emerge as a new process which give strong grounds why MAS specifically for micro-domain is needed. This is somehow in line with the call for a system that can assist users in generating micro-component using this MMT with better judgement.

Based on this ground, it is a meaningful effort to develop MicroMAS with the MMT as its domain of application for the manufacturability aspects of the micro-parts to be evaluated. Moreover, as there are no guidelines, standards or manuals to refer to in operating the MMT, the need to evaluate its functional characteristics such as uncertainties related to the MMT construction is imperative. In this context, there is a clear need to understand the influence of the errors stemming from the MMT construction on the geometrical accuracy of the machined micropart.

In this paper, the development of the UEM was considered to analyse the influence of the occurred errors in constructing the MMT on the geometrical accuracy of the machined micro-parts. Furthermore, it also allowed on understanding of how these errors are transferred into kinematic (tool path generation) flaws. However, the errors occurring/generated during machining (e.g. tool deflections, tool wear, vibrations) are not considered in this study. Besides developing a model/method that can predict errors of a (custom-made) machine tool, the results from this analysis is proposed to be integrated into the MicroMAS. The integration can portray the real condition of the MMT in the developed MicroMAS. For this reason, the effect of flaws in the MMT construction is taken into consideration in determining the MIs.

2 UNCERTAINTY EVALUATION ANALYSIS

Uncertainty of measurement (UEM) is defined by VIM (1993) as a parameter associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand. There are various procedures and concepts of uncertainty evaluation were proposed and discussed, but in 1993 the publication of Guide to the Expression of Uncertainty in Measurement (GUM) (Ridler et al. 2007) offered a unified method for the evaluation and expression of measurement uncertainties that has been accepted by almost all calibration services worldwide and has become a standard in the field of metrology (von Martens 2002, Kessel 2002). The basic approach of GUM is to describe a measurement using a model in the form of functional relationship between input and output quantities (Ridler et al. 2007). The input quantities are defined as the aspect that actually determined during measurement process while output quantities describe the result of the measurement.

UEM has been developed to understand the influence of the errors in constructing the MMT on the geometrical accuracy of the machined micro-parts. In any micro-machining domain, there are many aspects (e.g. machining parameters, machine tool characteristics, materials, and tooling) to be taken into consideration, which might not be important in the macro-machining area. Therefore, it is important to analyse any errors related to the construction of the MMT; these errors might not be of high importance in the case of using a conventional macro-machine tool but in this case it can significantly affect the quality of the machined micro-parts. The results from this analysis are proposed to be integrated into the MicroMAS. The integration can portray the real condition of the MMT in the developed MicroMAS. For this reason, the effect of flaws in the construction is taken into consideration in determining the Manufacturability Indexes (MIs) which is the major output of MicroMAS. MIs reflect the relative ease of machining of the component based on associated ratings of various aspects such as PF characteristics, surface roughness, tool dimension, tolerances, machinability of selected materials and also uncertainty effect in machining the micro-feature using the custom-made 4-axis MMT.

The analysis of the UEM is carried out in GUM Workbench which is a software tool for evaluation of uncertainties in measurements. Basically, the approach taken to develop the UEM is divided into three main phases: model development, model analysis and finally simulation and validation which are based on the ISO GUM (GUM 1993, Choi et al. 2003).

From the analysis, four sources of main errors have been identified which are: errors due to the MMT construction; errors related to evaluation of workpiece reference point; errors related to temperature variations and errors originating from positioning inaccuracies of each table. In order to evaluate the uncertainties stemming from the identified errors, the uncertainty model/equations are generated based on the spiral milling tool path in machining a cylinder. The model and methodology developed in analysing the errors above provide a proof that uncertainty analysis is able to understand the sources of errors from a custom-made machine tool that affect the quality of the final machined part. Moreover, once this model/methodology is developed, the geometrical errors can be evaluated in any situation when other (more) complex surfaces are generated.

Furthermore, in order for the developed MicroMAS to mirror the real condition of the MMT in the system, the impact of UEM analysis is taken into consideration for calculating the Manufacturability Index for Single Feature Analysis (MI_{SFA}). The Manufacturability Index for Uncertainty Evaluation Model (MI_{UEM}) is introduced and being considered in the MI_{SFA} formula for each identified primitive feature (PF). With this scheme, the manufacturability analysis in MicroMAS is more significant as it consider the uncertainty effect in machining the shape/form of the PF.

3 MICRO-MANUFACTURABILITY ANALYSIS SYSTEM

The development of the system is based on the three-step unidirectional which was divided into three modules/components: i) data input module; ii) manufacturability assessment module; iii) output generation module. The data **input module** is where all the relevant and related data were feed into the system. In this study two approaches were selected and combined which were *the user-system interaction* and *collection of related manufacturing information*. In the *user-system interaction* method the system prompts user with enquiry leading towards the collection of related information. While for the second method, the users are allowed to choose related data and parameters from the manufacturing information in the system's database.

The *Ruled-Based System (RBS)* was implemented to assist the decision making in the **manufacturability assessment** through the IF-THEN clauses. It helps to control the analysis of MicroMAS and represents the systems' knowledge base via logical combinations. RBS has been applied in manufacturing based inference engines because the IF-THEN rules are similar to common sense logic (Kusiak et al. 1988). Moreover, the concept of RBS and IF-THEN clauses can be implemented in any programming language or software packages including VB. In this study, the related rules and conditions correlated to micro-milling and primitive features elements are saved in the form of IF-THEN clauses. All the rules and conditions stored in database are interactively being searched based on IF-THEN clauses in order to determine which rules satisfy the inputs.

Finally in the third module which is the **output generation**, it provides the outputs from the manufacturability assessment such as redesign suggestion, overall MI and selection of materials. This result was displayed in various type of interface (e.g. pop-up window, reports, forms) generated using VB. The database is the medium where all the data and information needed for the analysis is stored; it was developed using Microsoft Access (MS ACCESS) and linked to the VB. Figure 2 illustrated the relationship between the software (VB.NET, MS ACCESS, GUM Workbench) and machining experiments. All related manufacturing information and rules are embedded in the database to be used as guide for assessing the manufacturability of the proposed design.

4 IMPLEMENTING UEM IN MICRO-MAS

In order to enhance the capacity of MicroMAS in assessing manufacturability aspects, the results from uncertainty evaluation towards the MMT will be integrated in the system's database. This is to fully understand the capabilities of the MMT which is the main scope of the developed MicroMAS. This analysis provides the opportunity to partly portray the real condition of the MMT in the developed MicroMAS. For this purpose, it is proposed to integrate the results from the UEM analysis in the MicroMAS by taking into consideration the uncertainty effect in machining the particular form/shape of PF in calculating the manufacturability indexes (MI) in MicroMAS. As the analysed micro-part in MicroMAS is being decomposed to primitive features (e.g. box, cylinder, sphere), in order for its manufacturability aspect to be assessed, the uncertainty effect is suggested to be integrated in the Single Feature Analysis (SFA) phase.

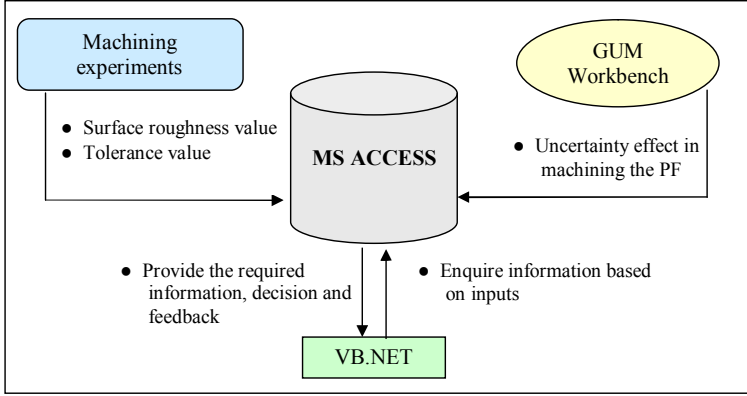


Figure 2: Schematic of relationship between the VB.NET, MS ACCESS, GUM Workbench and Machining experiments

4.1 Uncertainty effect in machining the primitive feature (MI_{UEM})

MI_{UEM} is implemented to partly reflect the real condition of the MMT which is the main domain of the MicroMAS implementation. It considers the uncertainty effects in machining the PF based on the UEM analysis on the occurred errors stemming from the construction of the MMT which affects the accuracy of the forms/shapes of the machined micro-features (e.g. PF). From the analysis and the generated UEM results (that gives the expected uncertainties in form/shape machining), it can be concluded that the smaller the size or dimension of the PF, the bigger the impact of this uncertainty impact towards the machined forms/shapes.

The foundation of MI_{UEM} index range is divided into a series of different features size intervals according to the size of the proposed micro-slots and thin walls. The index range for the MI_{UEM} is generated based on the expanded uncertainty value obtained from the UEM analysis in machining the cylinder using the spiral milling tool path. The nominal value(s) for MI_{UEM} for each interval is determined based on the average value of the obtained expanded uncertainty. As an example, for feature sizes between 0.5 and 1.0 mm, the nominal value selected (S) is $0.0055\mu\text{m}$. Based on the approach in determining the MIs (Equation 1), if the uncertainty effect selected by the user for the particular PF (N) is $0.0085\mu\text{m}$, then the MI_{UEM} is equal to 1.55. This is derived from the calculations of 0.0085 divided by 0.0055 and the level of manufacturability in this case is *Easy to Manufacture*.

$$MI_{UEM} = N/S \quad \text{Equation 1}$$

In calculating the MI_{SFA} , MI_{UEM} is incorporated for each identified primitive feature (PF) as presented in the formula below (Equation 2).

$$MI_{SFA} = \frac{\sum K_i \cdot MI_i}{5}, \quad \text{(Equation 2)}$$

Where i = PF, Ra, TOL, DIM, UEM

In this paper, the UEM development was analysed based on the machining of a cylinder in the MMT using a spiral milling tool path. Even though the impact of the generated error can be considered small and insignificant towards the geometrical accuracy of the machined micro-part, it is a value added approach to take this effect into consideration as it provides a better judgement towards

the determination of the MIs. Assumption has been made that the smaller the size or dimensions of the PF, the bigger the impact of the uncertainty. Furthermore, the average of the expanded uncertainty from the 30 repetitions of cutting time is considered as the nominal value for the MI_{UEM} . Therefore, as a conclusion, the calculation of MI_{SFA} has taken into consideration the uncertainty effect by introducing it into the formula (Equation 1) and the details of the MI_{UEM} range value was presented in Table 1.

Table 1: Index ratings for MI_{UEM}

Feature size (mm)	<div style="display: flex; justify-content: space-around; align-items: center;"> <div style="border: 1px solid black; padding: 2px 10px;">≤ 0.5</div> <div style="border: 1px solid black; padding: 2px 10px;">1.0</div> <div style="border: 1px solid black; padding: 2px 10px;">> 1.0</div> </div>		
	<div style="display: flex; justify-content: space-between;"> Harder to manufacture Easier to manufacture </div> <div style="text-align: center; margin-top: 5px;"> $\longleftrightarrow$ </div>		
	Uncertainty effect (μm)		
	0.0 – 0.5	0.0035	0.0065
0.5 – 1.0	0.0025	0.0055	0.0085
1.0 – 1.5	0.0020	0.0045	0.0075
1.5 – 2.0	0.0015	0.0035	0.0065
> 2.0	0.0010	0.0030	0.0045

4.2 Interface of MicroMAS

Figure 3 demonstrates the main interface where the input from user is collected. A guideline for entering and using this interface is provided by selecting the button ‘TO DO’. A pop-up window showing the guidance to fill in the form and assess the preliminary result of the input is also presented. Figure 3 shows the data input for PF_8 of the micro-component. Fundamentally, there are five important steps involved in the input mechanism and SFA analysis as pictured in Figure 3. Manufacturing related details such as the process involved (micro-milling), diameter of the tools and part quality measures (tolerance, surface finish and **uncertainty**) in generating the PF are required at Step 4. For the part quality measures, in order to assist the user in determining the suitable and appropriate MI_{Rb} , MI_{TOL} and MI_{UEM} , each button provides a related guideline. A pop-up guideline for MI_{UEM} is to guide the user with value for harder, medium and easy to manufacture and calculating the MI_{UEM} based on Equation 1. The MI_{Rb} , MI_{TOL} and MI_{UEM} are determined based on the related input in each guideline window and the indices scheme described in Table 1.

5 CONCLUSION

From here, it can be concluded that the implementation of the results from the UEM analysis mirrored the real condition of the MMT in the developed MicroMAS. This is done through the consideration of calculating MI_{UEM} in MI_{SFA} for each identified PF in the selected micro-component. The implementation provides user with assistant in analysing the generated micro-component based on the impacts of UEM towards machining the micro-component on the MMT. It offers user facility to generate the manufacturability index (MIs) of the micro-component to portray the level of its manufacturability. In the future, it is proposed for the affected identified errors in the UEM to be also implemented in the MicroMAS to provide more accurate MI_{UEM} value.

ACKNOWLEDGMENTS

The author is grateful for the support of the University of Nottingham where the research was carried out.

Data Input (MICROMACHINE TOOL)

MANUFACTURABILITY ANALYSIS SYSTEM for MICRO MACHINE TOOL

LOAD

Step ONE

Id Component: 1

Number of PF: 8

Material: Titanium Alloyed I

INFORMATION

Manufacturability index for each primitive feature is based on the single feature index, dimension, tolerance and surface roughness index. $MISFA = (\sum K_i^* M_i) / 4$, where $i = PF, Re, TOL, DIM$

Coupled Feature Analysis

Step TWO

Id PF: 8

PF Type: Box

Orientation: Boss

Side Angle: 0

Shape: Straight

Step THREE

Height: 0.15

Length: 0.2

Width: 1.4

End Corner: Sharp

Step FOUR

Process: Milling

Tool Diameter: 0.5

MITOL: 1.67

MIRa: 1.28

MITEM: 0.86

Step FIVE: ANALYSIS

K_i (Weight Factor): 0.9

MITOL: 1.5

MIRa: 1.3

MIDIM: 0.5

MIPF: 0.9

MITEM: 0.7

Single Feature Analysis

Calculate MISFA: 0.98

Stiffness Ratio: 0.14

<<FIRST <PREVIOUS 8 of 8 NEXT> >>LAST>>

To DO Open File

Figure 3: Main interface of MicroMAS

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DEVELOPMENT OF A NEURAL NETWORK MATHEMATICAL MODEL FOR DEMAND FORECASTING IN FLUCTUATING MARKETS

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ABSTRACT

Research has shown that Neural Networks (NNs) when trained appropriately are the best forecasting system compared to conventional techniques. Research has shown that there is no system to accurately forecast sudden changes in demand for a given product. This paper reports on the development of a recovery method when a sudden change in demand has taken place. This error in forecasting demand leads to either excessive inventories of the product or shortages of it and can lead to substantial financial losses for the company producing or marketing the product. Two recovery methods have been developed and described in this paper: RZ recovery and Exponential Smoothing (ES). In the RZ recovery once a sudden change has taken place, a 'soft' Poke-Yoke (PY) system is setup warning the company that the normal forecasting system can no longer be relied upon and a recovery system needs to be initiated, with re-forecasting initiated.

Keywords: forecasting, artificial neural network, exponential smoothing.

1 INTRODUCTION

The first task was to design an experiment to demonstrate that the RZ recovery would work and that it is a more accurate method of demand forecasting than the existing forecasting systems, in fluctuating periods, for demand for a product. In previous experiments it was shown that neural networks are the most accurate demand forecasting methods (Ziarati, 2003; Urkmez et al, 2007, 2008; Akdemir, 2007, 2008). In terms of accounting for recovery and taking account of past events it is known that ES techniques have been used in predicting demands in fluctuating markets with some success in the past. To this end, a conventional Exponential Smoothing (ES) system is applied to calculate the demand for the product during a fluctuation period in the market for a given product. The result has shown the RZ recovery is more accurate than ES techniques and this recovery system would help to address the sudden change in demand for given products and helps to make the inventory system more efficient ensuring that the excessive over supply or shortages for a given product are kept to a

minimum. Once the market has settle down the PY would effectively stop the recovery system and automatically reconvene the normal forecasting operations. The development of dual forecasting system, Neural Network for general prediction of demand for products and the RZ recovery for sudden changes, is considered an innovative approach. Whilst the prediction has shown to be more accurate and the risk of significant possible errors reduced, the proposed system is still a forecasting model and reliability still an issue.

2 DESIGN OF EXPERIMENT

To design an experiment there was a need to identify a set of data which could be used to test the two recovery approaches. The main requirement in the design process was that the data chosen should have at least have a major sudden change in demand for a given product(s). As two of the authors are associated with shipping companies a decision was made to use the Baltic Exchange Dry Index (BDI) values for this investigation. BDI is a measure of capacity needs for various types of ships (World fleet Grand total). This data is organized monthly and it is shown in a graphical form in Figure 1. It contains the demand for ships from November 1999 to April 2009. The data for November to January 2000 has been used for training the NN.



Figure 1: Baltic Exchange Dry Index

Forecasting BDI values three types of conventional methods were used: regression, exponential smoothing and NNs. There are many other techniques which in the majority of cases either rely on one of these techniques (or a variation) or a combination of them for example correlation, time series and so forth. There are several other methods such as percentage errors, probability methods, etc. A good account of these methods and their accuracy is given in Ziarati (2003).

In the majority of cases there is not sufficient data to predict accurately the future demand for a product or service. To this end, neural network systems have become more popular (Holland, 1975). However, the main reason for the popularity and recent prominence of neural networks is that they are basically learning mechanisms and are capable of handling a large amount of data and coming up with reliable outcomes provided the network is carefully constructed, trained and tested. This ability to learn 'seemingly large amount of abstract data and to interrelate different sets of information' makes them ideal tools for forecasting (Ziarati, 2003; Chua and Yang1988).

The theory of forecasting techniques including how the neural network works is fully described in Ziarati (2003). The purpose of the work presented here is to establish if methods used by Ziarati can be adapted to predict supply and demand for sea transportation (World Fleet Grand Total) and indexes such as BDI.

3 NEURAL NETWORK

The neural models are generally based on the perceived work of the human brain. The artificial model of the brain is known as Artificial Neural Network (ANN) or simply Neural Networks (NNs). The network is composed of large numbers of neurons and their intra-and inter-connections. The neurons operate collectively and simultaneously on most for all data and inputs which performs as summing and nonlinear mapping junctions. There is several kinds of neural network topology.

Generally, the feed-forward multilayer neural networks topology and back-propagation training algorithm are commonly used for neural network applications.

Multi-layer ANN consists of multiple layers of computational units, usually interconnected in a feed-forward way. Each neuron in one layer has directed connections to the neurons of the subsequent layer. In many applications the units of these networks apply a sigmoid function as an activation function.

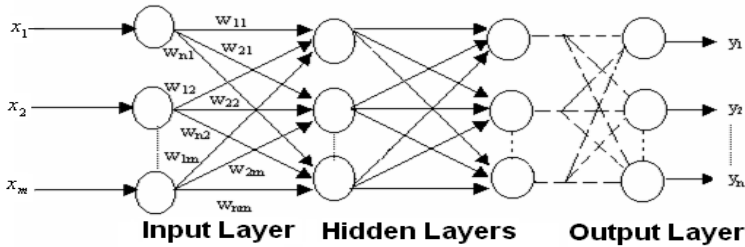


Figure 2: Multi- layer feed forward ANN

Multi-layer networks use a variety of learning techniques, the most popular being *back-propagation*. Here, the output values are compared with the correct answer to compute the value of some predefined error-function. By various techniques, the error is then fed back through the network. Using this information, the algorithm adjusts the weights of each connection in order to reduce the value of the error function by some small amount. In this research work, a multi-layered, feed forward neural network architecture with two hidden layers as shown in Figure 2. This neural network model has an extra hidden layer named pre-processing layer. It is allocated between the input layer and main hidden layer. In the input layer we have 17 neurons representing 4 independent variables, one dependent variable and 2 trend factors extracted from the independent variable. Historically, the last 3 values of each independent and the dependent variable were given to the neural network. In the first hidden layer, pre-processing layer, there are 10 neurons. In the second hidden layer there are 5 neurons. There are two outputs which are the predicted value of the total world dry bulk fleet and the validation value for representing the reliability of the results of the neural network.

It is expected that the neural network finds the relationships between the input parameters and the output parameters by adjusting its weights and biases. This neural network has three weight matrices and three bias vectors. Dimensions of the weight matrices and bias vectors depend on the architecture of the neural network. Here, U is a weight matrix with the size of 17×10 between the input layer and pre-processing layer, V is another hidden layer weight matrix with the size of 10×5 between the pre-processing layer and the main hidden layer and W is the last weight matrix with size of 5×2 between the main hidden layer and the output layer exist in this neural network structure. A number of the elements of the first weight matrix is decreased from 170 to 34 by choosing the proposed connection topology between the input layer and the pre-processing layer. It is supposed that, in a given time, the world fleet grand total value depends on its historical values and the historical values of the other independent variables. Forecasting results with ANN is shown in Figure 3.

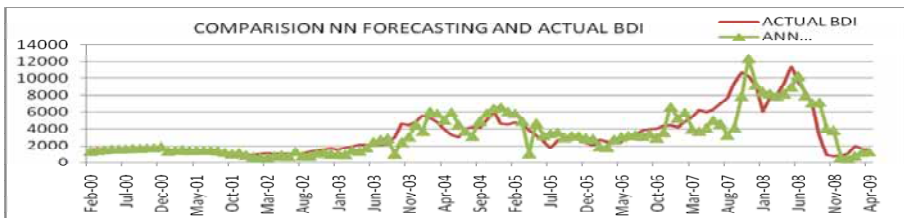


Figure 3: Forecasting with Neural Network

4 EXPONENTIAL SMOOTHING MODELLING

It is a very popular scheme to produce a smoothed time series. Whereas in Single Moving Averages the past observations are weighted equally, Exponential Smoothing assigns exponentially decreasing weights as the observations get older. Exponential Smoothing schemes weight past observations using exponentially decreasing weights. In other words, recent observations are given relatively more weight in forecasting than the older observations. In the case of moving averages, the weights assigned to the observations are the same and are equal to $1/N$. Where N is number of observation. In exponential smoothing, however, there are one or more smoothing parameters to be determined and these choices determine the weights assigned to the observations. There are three exponential techniques commonly in use such as Single Exponential Smoothing (SES), Double Exponential Smoothing (DES) and Triple Exponential Smoothing (TES). In this study, all these three exponential smoothing techniques are reviewed and applied to BDI data forecasting as shown in Figure 4, and the results with RZ recovery technique is shown in Figure 5.

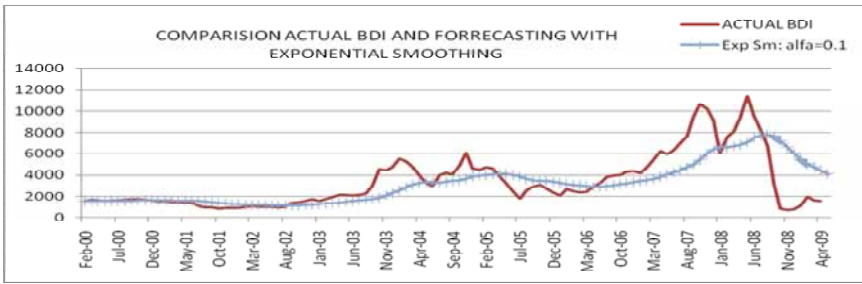


Figure 4: Forecasting Using Exponential Smoothing

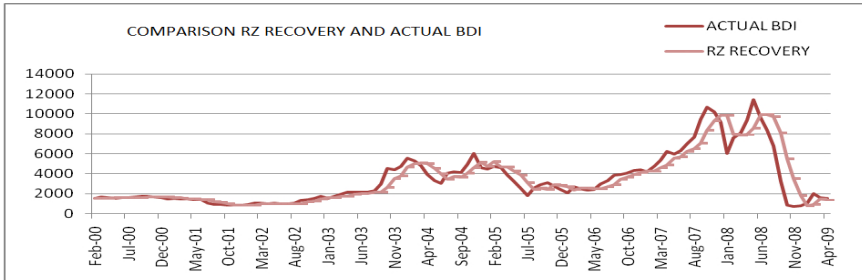


Figure 5: Forecasting Using RZ Recovery

4.1 Single Exponential Smoothing Model

For any time period t , the smoothed value S_t is found by computing:

$$S_{t+1} = \alpha y_t + (1 - \alpha)S_t \quad 0 \leq \alpha \leq 1$$

where S_t stands for smoothed observation, and y_t stands for the original observation. This is the basic equation of exponential smoothing and the constant or parameter α is called the smoothing constant. The subscripts refer to the time periods, $1, 2, \dots, n$.

4.2 Double Exponential Smoothing Model

Single Smoothing (short for single exponential smoothing) does not take into consideration if effects of trend is required to be taken into consideration as there is only one single coefficient α . This

situation can be improved by the introduction of a second equation with a second constant γ , which must be assigned in conjunction with α . Here are the two equations associated with Double Exponential Smoothing:

$$S_t = \alpha y_t + (1 - \alpha)(S_{t-1} + b_{t-1}) \quad 0 \leq \alpha \leq 1$$

$$b_t = \gamma(S_t - S_{t-1}) + (1 - \gamma) b_{t-1} \quad 0 \leq \gamma \leq 1$$

Note that the current value of the series is used to calculate its smoothed value replacement in double exponential smoothing. There are a variety of schemes to set initial values for S_t and b_t in double smoothing. S_1 is in general set to y_1 . The first smoothing equation adjusts S_t directly for the trend of the previous period, b_{t-1} , by adding it to the last smoothed value, S_{t-1} . This helps to eliminate the lag and brings S_t to the appropriate base of the current value. The second smoothing equation then updates the trend, which is expressed as the difference between the last two values. The equation is similar to the basic form of single smoothing, but here applied to the updating of the trend. The one- and m- period-ahead forecast is given by:

$$F_{t+1} = S_t + b_t, \quad F_{t+m} = S_t + mb_t$$

4.3 Triple Exponential Smoothing Model

If the data include trend and seasonality then double smoothing will not be effective. To this end, a third equation will have to be introduced to take care of seasonality (sometimes called periodicity). The resulting set of equations is called the "Holt-Winters" (HW) method after the names of the inventors. The basic equations for their method are given by:

$$S_t = \alpha \frac{y_t}{I_{t-L}} + (1 - \alpha)(S_{t-1} + b_{t-1})$$

$$b_t = \gamma(S_t - S_{t-1}) + (1 - \gamma)b_{t-1}$$

$$I_t = \beta \frac{y_t}{S_t} + (1 - \beta)I_{t-L}$$

$$F_{t+m} = (S_t + mb_t)I_{t-L+m}$$

Where y is the observation, S is the smoothed observation, b is the trend factor, I is the seasonal index, F is the forecast at m periods ahead and t is an index denoting a time period. α, β and γ are constants that must be estimated in such a way that the MSE of the error is minimized. To initialize the HW method we need at least one complete season's data to determine initial estimates of the seasonal indices I_{t-L} . A complete season's data consists of L periods. The trend factor also needs to be estimated from one period to the next. To accomplish this, it is advisable to use two complete seasons; that is, $2L$ periods. All results with the techniques mentioned such as ANN, ES and RZ recovery shown in Figure 6.

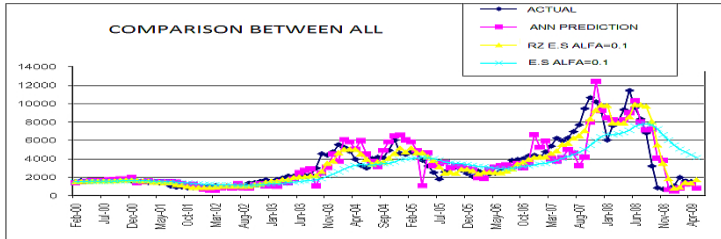


Figure 6. Forecasting with Triple Exponential Smoothing

5 CONCLUSIONS

When there are sudden changes in demand for a given product, this sudden change should be identified using a form of a PY and corrective action should be taken while abnormal fluctuations are taking place. In this experiment a PY system was introduced and two distinct corrective action methodologies, one based on ES and the other one on the RZ recovery were presented. The advantage of recovery system is that in addition to offering a mechanism for correcting demand forecast it provides an opportunity to make the necessary corrections to inventory of the product. One other benefit is that the inventory is taken into consideration when computing the forecast demand for the product. There are no recovery systems for when sudden change in demand are noted for a given product. It is a known fact that exponential smoothing takes account of past changes and this offers some corrective measures when forecasting demand for a product.

The RZ recovery, using the neural network mathematical model described in this paper as shown in Figure 6, by taking account of the last three actual data for any demand forecasting, proved to be more accurate than the very best of ES techniques.

This study has led to a successful outcome. Considering the results, it can be concluded that it is possible to identify a sudden change in the market for given product and have an effective software method for a corrective/recovery system for a more accurate prediction of demand for a given product. The RZ recovery system also allows inventory for the product to be continuously amended so that only the minimum numbers are produced after each demand forecast.

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EXPLOITING SUPPLIER CAPABILITIES TO MAXIMISE PRODUCT DESIGN OPPORTUNITIES IN THE FUZZY FRONT END ACTIVITIES

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ABSTRACT

This paper explores the Fuzzy Front-End (FFE), i.e. the first phase of the Product Design and Development process where a company formulates a product concept to be developed and decides whether or not to invest resources in the further development of an idea. Our goal is to understand how companies leverage supply chain capabilities to improve product design opportunities in order to obtain optimized product concepts in the FFE. From the analysis of our pilot study, the results suggest that FFE is organized differently depending on design requirements and supply chain capabilities and that matching design requirements with supplier capabilities during the FFE improves performance. Therefore, the findings indicate that the proposed Conceptual Framework has the potential to be used by companies to design their FFE and to enhance the use of supply chain capabilities in their product design activities.

Keywords: Fuzzy Front-End, Design, Supply Chain.

1 INTRODUCTION

Aligning supply chain with product design is a fundamental and essential process for any business and it brings relevant benefits to companies (Brun et al., 2013; Pero et al., 2010). As stated by Doyle and Broadbridge, (1999), it is through the product design-supply chain interface that ideas are transformed into products for customers. Integrating suppliers into Product Design and Development (PDD) process is a way to pursue alignment. Suppliers integration in PDD had been widely analysed in relation to the phases of Product Development (Handfield, et al.1999; Johnsen, 2009).

The front-end of innovation, or what is often called the Fuzzy Front-End (FFE), presents one of the greatest opportunities for improving the overall innovation process. This stage, which is defined by Koen et al. (2001) as activities that take place prior to the formal, well-structured PDD (Cooper, 1990), is the target of increasing attention because of the widely-perceived lack of high-profit ideas entering the PDD process. In fact, effective idea management has the greatest impact on successful product innovation as great ideas can disappear into a “black corporate hole” (Cooper, 2011). During the FFE new ideas are generated and evaluated. How ideas are managed and implemented is more important than generating a high number of ideas (Koen et al., 2001), since organisations understand the need for creativity but only a few succeed in translating theory into practice (Majaro, 1992). In the FFE, suppliers and supplier managers can play a fundamental role in unlocking suppliers innovation capabilities, since as the recent study by Björk and Magnusson (2009) contends that idea providers with a high network centrality provide a better quality ideas due to the increased knowledge and information sources. Moreover, firms should take a pragmatic approach to fulfilling the need for customization by considering market requirements and supply chain constraints and opportunities together (Salvador et al., 2002). Despite this, there is a dearth in literature on how companies organize

the FFE to allow the involvement of main suppliers in order to increase design opportunities. This paper aims at tackling this gap in the literature. To this aim, a systematic review of approaches to FFE and suppliers involvement during the PDD process has been undertaken in order to develop a Conceptual Framework for the study. Then, a series of empirical case studies have been developed to explore the main findings. The study confirms the relevance of supplier capabilities during product development and it shows the critical role played by supplier capabilities on the FFE to increase design opportunities for product features.

2 LITERATURE REVIEW

According to Petersen et al. (2005), supply chain design should be determined during the PDD process, when product, process and information systems decisions are specified. Furthermore, the nature of relationships between customers, manufacturers and suppliers are often established early in the PDD process (Handfield and Bechtel, 2002; Ragatz et al., 2002). Early Supplier Inclusion or Involvement or Integration (ESI) during the PDD process, i.e. the general term used to define a form of vertical collaboration in which manufacturers involve suppliers at an early stage of product development projects (Bidault et al., 1999; Dowlatshahi, 1998), is an important coordinating mechanism for decisions that link product design, process design, and supply chain design together (Petersen et al., 2005). Research on ESI maintains that earlier involvement is always better (Handfield et al., 1999) and suggests that technology uncertainty can be mitigated through openly sharing cost and technology information with suppliers (Hagedoorn and Narula, 1996; Teece, 1986). Consequently, Ragatz et al. (2002) have developed a conceptual model to test the effect of elements of the supplier integration process on cost, quality and PDD time, under conditions of technology uncertainty. Handfield et al. (1999) proposed a model for achieving consensus on suppliers integration into PDD process providing a theoretical framework to assist outsourcing decisions. Since it is at the stage of FFE that critical and strategic decisions are made, not only with respect to the functionality of the product for the customer, but also the logistics, the packaging, the materials and technological processes, involving suppliers can be critical and relevant. Although many researchers present different categorizations of supplier involvement during the first phase of PDD process (Le Dain et al., 2011), how to involve suppliers in the FFE to increase idea management efficiency is still an open question.

3 RESEARCH FRAMEWORK

The study aims to answer to two main Research Questions:

1. How do companies organize the Fuzzy Front-End of Product Design and Development process to allow the involvement of main suppliers in order to increase design opportunities?
2. How does the organization of Fuzzy Front-End of Product Design and Development process change depending on variation of product, process and supply chain characteristics?

To tackle these Research Questions, a Conceptual Framework has been developed (see Figure 1).

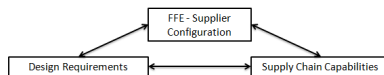


Figure 1: Conceptual Framework

FFE - Supplier Configuration: it represents the kind of integration with supplier in the FFE in line with Clark and Fujimoto (1991) and Petersen et al., (2003). It is composed of two variables, i.e. level of interaction and innovation learning. *Level of Interaction* represents the kind of communication between designers and suppliers. It can assume the two levels, shown in Table 1.

Table 1: Spectrum of “Level of Interaction” (readapted from Petersen et al., 2003)

Communication, discussions on the definition of the specific component	Partial / Full Integration, strategic collaboration with suppliers
↔	→

Innovation Learning is the level of responsibility assigned to the supplier and the exchange of information among team members (internal) and suppliers (external) to conduct the development

activity. The representation is through a couple of dashed edges arrows and values are reported in the Table 2 below.

Table 2: Spectrum of “Innovation Learning” (readapted from Petersen et al., 2003)

Supplier “makes to print”	Joint development activity, PDD team consults with supplier on project design	Design is primarily supplier driven
		

Combining the configuration variables in order to analyze different supplier involvement during the FFE, we report six theorized FFE – Suppliers Configurations shown in the following Figure 2.

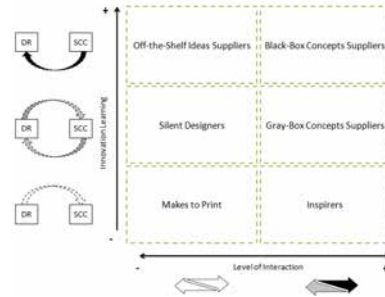


Figure 2: FFE - Suppliers Configurations (for the suppliers involved in FFE)

Design Requirements and Supply Chain Capabilities: represent product, process and supply chain characteristics considered during the FFE. Design requirements are: Technology, Materials / Processes, Intellectual Property Rights (IPR), Innovativeness / Lifecycle positioning, Architecture / Variety, Volume / Size, Form / Shape, Price / Costs. Supply chain capabilities that companies can exploit during the FFE are: Technology Capabilities, Manufacturing / Processes Technologies, Materials Technologies, Volume / Variety Capacity, ICT Capabilities, Logistics Capabilities, Lead Time Minimization, Efficient Cost Structures.

4 METHODOLOGY

In this study, we adopted multiple case study approach since, it is a very powerful method for building a rich understanding of complex phenomena (Eisenhardt and Graebner, 2007), that requires the capability to answer to “how” and “why” questions (Yin, 2008). In order to examine different product categories developed through PDD practices in various industries, we collected nine examples of product development projects from six different companies analyzed through field research and other four examples from literature case studies. The six case study were performed using a web-based questionnaire and in-depth interviews. In each company we interviewed one or two managers. The person interviewed was chosen among: Procurement Director, R&D Director, CEO, Purchasing Product Development Manager, Designers. The questionnaire allowed us to collect general data and the interviews were planned around a structure that permitted tracking the decision-making process involved in the development of a new product, with focus on the FFE. Secondary information was collected in the form of company reports (when available) and project-specific documentation. All interviews were tape-recorded and transcribed; generally, a telephone follow-up with the respondents was conducted to assess the outcomes and, in case, to gather missing data. Data and information gathered through the case studies were manipulated before being analysed. In particular, we applied data categorisation and data contextualisation. Therefore, the examples of projects we gathered in each case study was then classified according to the FFE-Suppliers Configurations matrix. In Table 3, we summarize main information reporting case study, source, example and relative supplier category of each case study from literature and field research.

Table 3: Case studies from field research and literature with examples of supplier involvement practice during the FFE

Case study	Industry	Revenues	Source	Example	FFE - Supplier Configuration
SMART	Automotive	€ 106 billion	Literature	Konzept-Wettbewerb	Gray-Box C. Suppliers
IKEA	Furniture	€ 27 trillion	Literature	Children's IKEA	Silent Designers
PHILIPS	Electronics	€ 24 billion	Literature	Innovative Products & "one roof" strategy	Gray-Box C. Suppliers
BANG & OLUFSEN	Electronics	€ 586 million	Literature	Key and System Suppliers	Gray-Box C. Suppliers
ARISTON THERMO	Home and water heating	€ 1,35 billion	Field Research	Hydraulic module	Silent Designers
DONDUP	Fashion	€ 65 million	Field Research	Silk Jeans	Inspires
MAX MARA F.G.	Fashion	€ 1,26 billion	Field Research	Upholstered Outerwear	Inspires
LUBE	Kitchen	€ 160 million	Field Research	Brava kitchen	Gray-Box C. Suppliers
				Adele kitchen	Black-Box C. Suppliers
MASERATI	Automotive	€ 588 million	Field Research	Seat Belt	Makes to Print
				Bridge	Gray-Box C. Suppliers
				Airbag System	Off-the-Shelf Ideas Suppliers
NISSAN	Automotive	€ 73 trillion	Field Research	Supplier Development Team (SDT)	Gray-Box C. Suppliers

5 EXPLORATORY CASE STUDIES FINDINGS

Answer to RQ1: By comparing the features the FFE - Supplier Configurations adopted in the analyzed examples, we provide answer to the first research question. In particular, during the FFE, Makes to Print and Silent Designers suppliers are managed in a similar way, similarly Gray-Box Concepts Suppliers and Black-Box Concepts Suppliers. The first group is characterized by a low Level of Interaction and primarily a poor responsibility assigned to suppliers during the FFE. On the other hand, the second group includes suppliers to which extensive responsibility for the design is given and suppliers are highly integrated. Interestingly, the main features of the two identified groups can be summarized readapting a classification proposed by Spekman et al. (2000). In particular, we refer to **Concept Dalliiances** for relations with supplier categories *Makes to Print* and *Silent Designers* whereas **Concept Alliances** include strategic partnerships with *Gray-Box* and *Black-Box Concepts Suppliers*. All main characteristics and information found through our study are outlined in Table 4.

Table 4: Characteristics of Concept Dalliiances and Concept Alliances (from Spekman et al., 2000)

Characteristic	Concept Dalliiances (Makes to Print / Silent Designers)	Concept Alliances (Gray-Box / Black-Box Concepts Suppliers)
Communication	Focus on main information and compliances, sharing limited to the project	Integration and high compatibility that supports close working
Commitment	Short-term agreements, limited to the duration of the project	Long-term agreements and joint development activities demonstrated by sharing of sensitive information
Interdependence	Low level of responsibility assigned to suppliers, both parties may behave opportunistically	Partners must co-operate in order to achieve their targets
Coordination	Limited and structured	Linked and fundamental to the future of the relationship
Effectiveness	Reactive suppliers that must respond quickly and exhaustively	Pro-active suppliers that must possess key competences needed and take own initiatives

This study, therefore, suggests that different approaches to supplier involvement should be used during the FFE, and that suppliers should have different characteristics depending on the kind of alliance pursued.

Answer to RQ2: The analysis performed on quantitative data from questionnaire revealed that Design Requirements and Supply Chain Capabilities have different importance during the FFE. Despite we analyzed companies from various industries that are characterized by different product, process and supply chain characteristics, there are some features that are generally considered essential. Specifically, fundamental Design Requirements are: Technology, Materials / Processes, Architecture / Variety and Volume / Size. The most important Supply Chain Capabilities are: Technology Capabilities, Manufacturing / Processes Technologies and Materials Technologies.

Other questionnaire results are related to PDD Project Typology. Comparing the literature with our exploratory case studies, we found that companies develop more collaborations with suppliers for incremental changes (product improvement in existing line or new product in existing line). In fact, they exploit external sources of expertise in order to acquire the necessary capabilities. For radical

changes (new line in existing market or new product/product line in new market) more distant and less frequent contacts or “weak ties” (Granovetter, 1973) are deemed important.

Moreover, observing questionnaire results, we identified two main groups of analyzed companies that highlight different product complexities and architectures. According to Salvador et al. (2002), the first group can be distinguished as “Component Swapping modularity” and is characterized by two main elements: product body and swappable components. Product variants are obtained by swapping components maintaining a basic body (kitchen, furniture, home-water heating). The second group contains products that have a more complex “Combinatorial modularity”. In fact, product variety is obtained through a combination of several components (automotive, audio systems).

Summarizing questionnaire and interviews results, we found that the relational features mentioned above in Table 4 can be directly linked to the architecture of the product; in particular, Component Swapping modularity requires Concept Dalliiances whereas Combinatorial modularity calls for Concept Alliances. For example, the interview with Lube R&D Director or the IKEA case study revealed that these firms generally manage short term agreements with suppliers during PDD process. We specify that kitchens or furniture are characterized by a body structure composed of a frame and swappable components that permit the generation of product variety (Component Swapping modularity). On the other hand, a car is an intuitive example of a product that have an architecture related to Combinatorial modularity. We observed that all automotive companies analyzed integrate main suppliers in order to obtain more business opportunities. Therefore, when companies develop different product modules or, in other words, pass from Component Swapping to Combinatorial modularity, they should enhance communication with their suppliers and the level of responsibility given to them. Hsuan (1999), for example, has shown that higher degree of modularization is possible when more collaborative forms of partnership are shared between the partners during PDD process.

6 CONCLUSIONS AND FURTHER DEVELOPMENT

We summarize the main implications observed through the related units of analysis as following:

1. PDD Practices and Product Categories: Two different approaches to FFE activities that imply related suppliers profiles can be clearly recognized; Differentiated importance levels are given to product, process and supply chain characteristics considered during the FFE (Design Requirements and Supply Chain Capabilities);
2. Project Typology: During the FFE, incremental PDD projects (product improvement in existing line or new product in existing line) imply a higher supplier involvement than radical PDD projects (new line in existing market or new product/product line in new market);
3. Product Architecture: There is a connection between modular product architectures and suppliers involvement within FFE activities.

The managerial implications involve the development of a structured configuration of the supplier involvement in the PDD process based on the project innovativeness and the characteristics of product architecture. Our approaches facilitate the definition of the different roles and levels of responsibility to be assigned to suppliers within FFE activities. In particular, two different approaches to FFE that we named **Concept Dalliiances** and **Concept Alliances** were outlined. These approaches define the main guidelines for the supplier involvement and coordination of FFE activities in order to obtain new business opportunities. The best strategy depends on the nature of innovation and the architecture of the product offered to the market. This strategy will allow companies from different industries to increase effectiveness and efficiency of PDD process exploiting supplier capabilities in order to generate added value ideas.

The main findings of the study are the starting point for further research on the issues of suppliers involvement and integration during the PDD process. The relevance of these topics deserves a more in-depth study of the ways in which manufacturing companies can take advantage of the skills and competencies of suppliers during the development of innovations.

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Enterprise Systems & Cloud Manufacturing

CHALLENGES OF CLOUD TECHNOLOGY IN MANUFACTURING ENVIRONMENT

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ABSTRACT

The rapid growth Information systems and advanced network technologies have significant impact on enterprises around the world. Enterprises are trying to gain competitive advantage in open global markets by using the latest technologies, along with advanced networks, to create collaboration, reduce costs, and maximize productivity. The combination of latest technologies and advanced manufacturing networks technologies lead to growth of new manufacturing model named Cloud Manufacturing which can shift the manufacturing industry from product-oriented manufacturing to services-oriented manufacturing. This paper explores the literature about the current Manufacturing problems, understands the concept of Cloud Computing Technology, introduces Cloud Manufacturing and its role in the enterprise, and investigates the obstacles and challenges of adopting Cloud Manufacturing in enterprises.

Keywords: Cloud Technology, Cloud Manufacturing, and Cloud Computing.

1 INTRODUCTION

The use of new technologies and networks are becoming critical success factors in any enterprise. Enterprises are trying to gain competitive advantage in global markets by using the latest technologies, along with advanced networks, to create collaboration. Manufacturing companies currently rely on many advanced network technologies, such as Agile Manufacturing, Network Manufacturing, and Manufacturing Grid to operate a single manufacturing task from the integration of distributed sources. These manufacturing networks enable collaboration and sharing of manufacturing resources between manufacturing units (Xu 2012).

Although manufacturers benefit from the implementation of state-of-the-art technologies in gaining advantage over competitors, there are problems in these existing network technologies that affect production within the manufacturing industry. These issues include the sharing of manufacturing resources, where the manufacturing resources cannot be distributed into the manufacturing network due to lack of manufacturing services management in the manufacturing network. Inability accesses the manufacturing hard resources (i.e. equipments) in the manufacturing network (Gao *et. al* 2013). Absence of knowledge sharing and distribution between manufacturing units, suppliers, customers, and partners to development strategies in how to enhance competitive advantage and in how to understand manufacturing practices within the industry (Xu 2012).

To address the issues affecting the industry, a new manufacturing model, called Cloud Manufacturing, is emerging. This model can provide and share manufacturing resources and

manufacturing capabilities as services to the users in enterprise. Cloud Manufacturing model is complex and involves many advanced technologies and networks that need to be integrated efficiently, and it affords the ability to exchange data and share knowledge among the different users (customer, suppliers, and partners), which can be an important factor to reduce costs, maximize productivity, increase in the utilization rate of resources, and create collaboration (Wang and Xu 2013). Also, it has the potential to exceed expectations with the right implementation; and it can change and restructure manufacturing systems in the manufacturing industry, and move it from production-oriented manufacturing to service-oriented manufacturing (Xu 2012).

2 AN OVERVIEW OF CLOUD COMPUTING TECHNOLOGY

The Cloud Computing Technology concept is changing the way of invented, developed, deployed, scaled, updated, maintained, and paid for information technology services (Marston *et. al* 2011).

There are variety definitions for Cloud Computing Technology, but one of the best and generic definition has been defined in 2011 by the National Institute of Standards and Technology (NIST). NIST define Cloud Computing Technology as “Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models”.

The relationship between traditional computing device and Cloud Technology can provide a better understanding of this new technology. Figure 1 demonstrates this relationship.

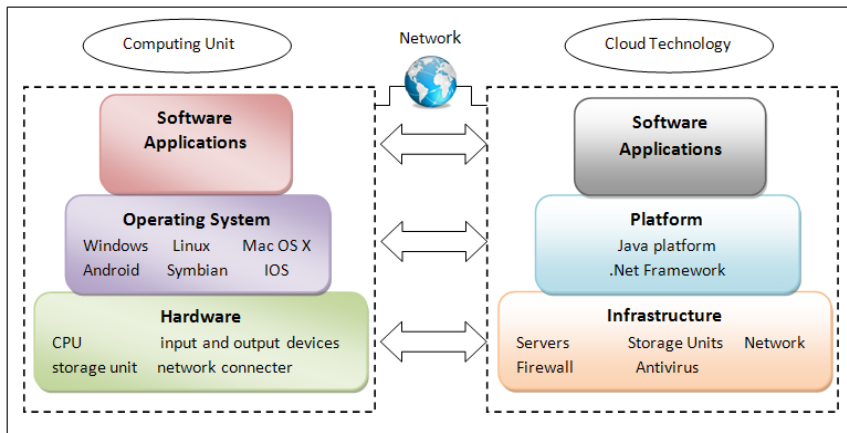


Figure 1: Relationship between traditional computing device and Cloud Technology

There are three main elements in traditional computing device, hardware, operating system, and software applications. Each element has a specific role in the computing device. The hardware consists of central processing unit (CPU), input and output devices, storage unit, and network capability. The CPU is responsible for all operations in the computing device, and network capability is connecting the computing device to the network for joining other computing device on the network. The operating system is a set of software programs to manage the application, and to control hardware devices in the computing device. The third element is software applications that exist in the computing device to perform tasks for the users.

Similarly, Cloud Computing Technology has same elements with different terminology, the Cloud Technology elements are infrastructure, platform, and software. The infrastructure consists of all the necessary services and facilities to provide computing resources for the users. The platform provides a development environment for developers to develop their own application, where a

developer user can write, run, upgrade, fix, and change his application. The final element provides software applications based on the needs of the user.

3 CLOUD MANUFACTURING

The role of technology in the manufacturing industry has become critical factor and it is fundamental in supporting technical and business processes. Today, the emergence of new technologies such as Cloud Computing, Internet of Things, Virtualization, and Web Services, with the help of existing advanced manufacturing networks, can shift the manufacturing industry from product-oriented manufacturing to services-oriented manufacturing. The combination of innovative technologies and existing manufacturing networks has created a new concept, called “Cloud Manufacturing”.

Cloud Manufacturing can define as a manufacturing model that depends on new technologies and advanced manufacturing networks to share the manufacturing resources and capabilities as services, and create collaboration with other users. Manufacturing resources refers to soft resources(workforce, software, knowledge) and hard resources(manufacturing equipments, monitor control devices, materials, transportations, storages), whereas manufacturing capabilities refer to ability to transform manufacturing resource into another form (design, production, management, communications, etc). The goal of Cloud Manufacturing is share the manufacturing resources and manufacturing capabilities to create collaborative work between customer, suppliers, and partners locally, nationally, and internationally.

3.1 Cloud Manufacturing Architecture

Lv (2012) proposed a architecture for Cloud Manufacturing consists of five layers:

Physical resource layer:

Includes all the manufacturing resources and manufacturing capabilities, and links those resources and capabilities to the global network by using technologies such as Internet of Things.

Virtual resource layer:

Prepare the manufacturing resources and manufacturing capabilities for the cloud environment by virtually encapsulating physical resources, and publishing them into the core service layer.

Core service layer:

Manages the cloud services of the encapsulation of manufacturing resources and manufacturing capabilities for the users (provider, operator, and consumer), hence: cloud services include registration, service booking, charge, and search.

Application interface layer:

Provide integration between the existing manufacturing application system and the cloud service in order to deliver a manufacturing application system according to user demands.

Application layer:

Provides access for users to request a Cloud Manufacturing service from any device (PC, laptop, smart phone), from anywhere (company, home, aboard).

3.2 Cloud Manufacturing Deployment Models

There are four types of deployment models in cloud environment, public cloud, private cloud, community cloud, and hybrid cloud. Each type is designed for specific situation that suitable for the enterprise (Marston *et. al* 2011).

Public Cloud:

A public cloud is offered services and infrastructure from off-site, third party service provider via the Internet. The advantage of this kind of cloud is reducing the cost of (IT) solutions in the enterprise. An example of public cloud that is used by many enterprises is the E-mail providers such as Hotmail.

Private Cloud:

A private cloud provides same services and infrastructure of the public cloud for the enterprise but within the enterprise. The access for the private cloud is limited to enterprises only. The key advantage for this cloud is ability of control the cloud infrastructure. Enterprises often prefer using private cloud for critical information.

Community Cloud:

A community cloud is shared and used by several enterprises that have the same mutual interests and concerns. For example, in United Kingdom all Government agencies may share computing infrastructure on the cloud to manage data related to citizens residing in United Kingdom.

Hybrid Cloud:

A hybrid cloud consists of two types of clouds, public cloud and private cloud. This cloud used by enterprises to determine how to distribute and share critical information, services and infrastructure within or outside the enterprise.

4 CLOUD MANUFACTURING CHALLENGES

Many enterprises, which implemented or trying to use Cloud Computing Technology, have major consideration about this technology. Today, most of enterprises that used Cloud Computing Technology have fears of putting their critical data and application in the Cloud due to trust issue (Chow *et al.* 2009), while Greenwood *et al.* (2010) state that the host of all data and applications in the Cloud environment will be impossible for any enterprise. They assume a combination of Cloud Technology and existing servers within the enterprise. Understating the challenges in Cloud Manufacturing can be a significant factor for adopting Cloud Manufacturing into enterprises. A few studies indicates key challenges in Cloud Manufacturing as shown in Figure 2 (Wyld and Maurin, 2009; Shade O *et. al.*, 2010; Marston *et. al.*, 2011; Ogunde and Mehnen, 2013)

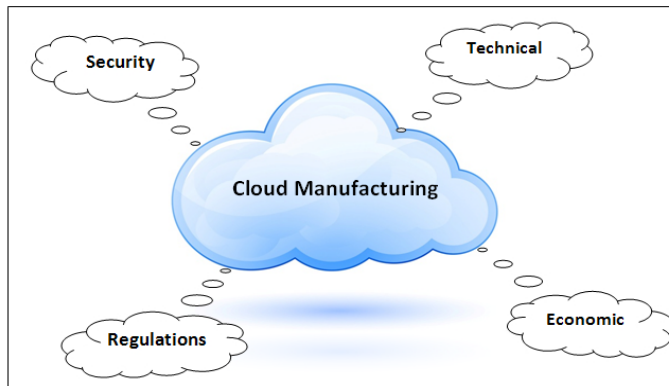


Figure 2: Cloud Manufacturing challenges

Most important challenge in Cloud Manufacturing is security, where many issues such as privacy, data deliver, data control, and hackers are the major issues of security in the Cloud environment, and many enterprises do not want adopt this technology for previously mentioned issues. A survey conducted in 2010 by Harris Interactive for Novell company shows that 91 percent are concerned about security issues in the public cloud, 76 percent believe data is more secure internally in IT departments in the enterprise premises. Also, the complexity of Cloud Manufacturing can create suitable environment for security breaches and losing control of data and applications that are critical for the enterprise.

Because of the complexly of Cloud Manufacturing system and involves many advanced technologies and networks that need to be integrated efficiently, many technical challenges exist in the cloud. Among these challenges, transform manufacturing resources and capabilities into cloud, network outage and system failures (availability), the ability to work together with different information systems, more than one cloud, and different software applications (interoperability), and easily grow of information system due to increase demand for cloud services (scalability).

Both of manufacturing resources and manufacturing capabilities are core of Cloud Manufacturing system, and it need many technologies such as Internet of Things and wireless sensors to coordinate

between Cloud Manufacturing system and manufacturing process. But the amount of data collected from different equipments and tools lead to overload in network and make it very slow for exchange data in Manufacturing Cloud system. Also, need more storage space into the cloud due to data collection of real-time manufacturing resources, and need more process resource from cloud to handle this data. All those issues can result in Cloud Manufacturing system failure.

Although, cloud providers invests a lot in their systems to grantee availability of the cloud systems, but there are many incidents, such as Gmail outage for 100 minutes in 2009, can create doubts about the cloud capabilities for delivering critical data and application for enterprises. The cloud providers guarantee deliver cloud services to customers under any circumstances, but sometimes enterprises can not access their data and cloud resources due to network outage and system failures. The outage may be permanent as provider company gone out of business or temporary as failure in provider company systems. Either way, fail to provide data and cloud resources can be disaster on enterprise, where the enterprise can not function without their data and cloud resources.

The aim of Cloud Manufacturing is to manufacturing resources and capabilities between different parties (manufacturing units, supplies, other enterprises, and customers), but to manage different information systems and different manufacturing systems under Cloud Manufacturing umbrella can be difficult task for both enterprises and cloud providers. For example, legacy systems are substantial irreplaceable in many enterprises, and it is costly and time consumer to put it into cloud. Moreover, many cloud systems architecture designed as closed systems, which prohibit to interactive with other cloud systems. Also, different cloud providers can create a vendor lock-in situation, where each cloud provider has its own way to run the cloud different from other providers. This limits the choices for enterprises to choose between other cloud providers in the market.

Availability, performance, and quality are the major concerns when enterprises using cloud services. The relationship between cloud provides and their customers need to be more efficient and effective by using standards, agreements, and regulations to know the responsibilities and duties of each party in Cloud Manufacturing system. Lacking control of the data and it location in the cloud may creates conflict with regulations laws in enterprise's country, an example for this dilemma, European Union and American countries have laws prohibits moving certain data types outside the enterprise's country.

The cloud provides need to ensure their customers about their services by using Service Level Agreement(SLA). Until this day, there is no official standard for Cloud Computing Technology, but there ongoing work from International Organization for Standardization (ISO) for standardization of Cloud Computing Technology. The standard is expected to be a guideline or code of practice for Cloud Computing Technology.

From the economic perspective, the purpose of using Cloud Manufacturing is to reduce the cost of investment in IT. Cloud Technology allows enterprises, especially SMEs, to use computing resources and capabilities at low cost. A research indicates that the implementation of cloud technology in enterprise has financial benefits reach to nearly 37%. However, the implementation of Cloud Manufacturing can raise the cost of using network communication (bandwidth) to send and receive data from the cloud. Moreover, Using Cloud Manufacturing for large enterprises can be costly due to need of more Cloud resources for their large projects. Also, possibility of switching Cloud providers because of dissatisfaction of Cloud provider services could be costly and time consumer for the enterprise due to difficulty extract the data existing in the cloud.

5 CONCLUSIONS

Cloud Manufacturing is one of the emerging technologies in the field of Information system, and has a significant impact in manufacturing industry by sharing the manufacturing resources and capabilities as services, and creating collaboration. However, there are many challenges that can be obstacle of Cloud Manufacturing implementation in manufacturing industry. Enterprises have their suspicions and fears about Cloud Manufacturing capabilities. This paper focused on some important challenges regarding security, technical, organization, and economic. It is very important to understand and provide solutions to these challenges before jumping into Cloud Manufacturing.

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A COST ENGINE SYSTEM FOR ESTIMATING WHOLE-LIFE CYCLE COST OF LONG-TERM DIGITAL PRESERVATION ACTIVITIES

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ABSTRACT

This research paper presents a cost engine system that estimates the whole life cycle cost of long-term digital preservation (LTDP) activities using cloud-based technologies. A qualitative research methodology has been employed and the activity based costing (ABC) technique has been used to develop the cost model. The unified modelling language (UML) notation and the object oriented paradigm (OOP) are utilised to design the architecture of the software system. In addition, the service oriented architecture (SOA) style has been used to deploy the function of the cost engine as a web service in order to ensure its accessibility over the web. The cost engine is a module that is part of a larger digital preservation system and has been validated qualitatively through experts' opinion. Its benefits are realised in the accurate and detailed estimation of cost for companies wishing to employ LTDP activities.

Keywords: cost engine, long-term digital preservation, whole life cycle cost, cloud computing.

1 INTRODUCTION

Digital preservation is defined as a series of activities that enables the continuous access to digital information for as long as required. It involves the planning and application of preservation techniques and technologies to ensure the active management and accessibility of digital information. Becker et al (2009) suggests that digital preservation is more complex than traditional preservation. Unlike traditional objects (e.g. photographs, books) where users can immediately access its content, digital objects are dependent on both the hardware and software environment. However, these environments are subjected to rapid evolution due to technological obsolescence which threatens continuous access to digital content. Estimating the accurate cost for preserving digital information has become a challenge due to the need to account for uncertainties and obsolescence issues on cost. However, understanding the cost for LTDP activities will enable companies to make better decisions in selecting the most appropriate preservation solution from a cost perspective.

In recent times, cloud computing is rapidly becoming an interesting technique for supporting digital preservation. With easy access from any location and significant reduction of initial investment costs, cloud computing is gradually becoming a preferred preservation approach (Badawy et al. 2012). Cloud computing is described as the utilisation of computing resources that are distributed over a network (i.e. the Internet) or a service. End users accesses cloud-based applications via a light-weight application and user's data are stored on remote servers. There are many types of cloud deployment

models such as public cloud, private cloud, hybrid cloud and community cloud. All has their advantages and disadvantages and companies should carefully study the cost/economic implications of these cloud deployment models before making decisions on LTDP projects. It is important to identify that cloud computing is considered as an enabler of digital preservation (i.e. storage option) and it is not on its own enough for performing LTDP activities.

Enabling kNowledge Sustainability, Usability and Recovery for Economic Value (ENSURE) is an EU-FP7 (Framework Programme Seven) project focused on providing a total solution for LTDP. The ENSURE system is focused on serving three main business sectors. These are namely financial, healthcare and clinical trials. Previous LTDP initiatives has traditionally been geared towards the scientific and heritage sectors. Thus, the aforementioned sectors ENSURE is targeting is unique and so is the cost engine system being developed for this purpose. The ENSURE system is comprised of three main engines, the first is the cost engine (CE), followed by the economic performance assessment engine (EPAE) and lastly, the quality engine (QE). These engines are integrated into the larger architecture of the ENSURE system as illustrated in Figure 1. The purpose of these engines are to provide crucial decision-support to users wishing to employ LTDP activities. This includes evaluating and optimising the cost and benefit of many preservation plans to determine the most appropriate in terms of cost and quality. The ENSURE architecture has several modules communicating together with a wide variety of functionalities.

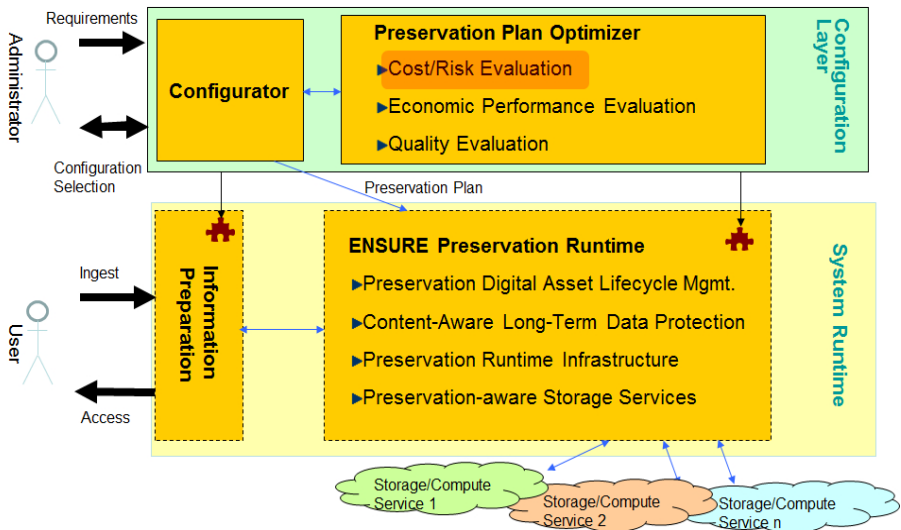


Figure 1: ENSURE System Architecture (ENSURE 2013)

As illustrated in Figure 1, the cost engine is a module within the configurator layer of the ENSURE system. This research paper describes the cost engine module of the ENSURE system and outlines how it can be used as a crucial decision-support mechanism for estimating costs for LTDP activities on the cloud.

Although there have been many attempts to develop cost models within LTDP, these cost estimating systems are usually not described in detail and often do not cover the ‘whole life cycle cost’ of LTDP. Some are focused on storage only, others are focused on other aspects of LTDP activities (e.g. ingest, data management). Another limitation is that most of these cost systems are geared towards the scientific and heritage sectors. There is lack of research focused on developing cost estimation systems for LTDP activities for the financial, healthcare and clinical trials sector. Thus, this research paper presents a cost engine system that aims to estimate the whole life cycle cost

for LTDP activities for the financial, healthcare and clinical trials sector in order to enable crucial decision-support for users in these sectors.

2 RELATED WORK

There are many projects focused on developing cost models for estimating LTDP costs. However, most of these cost models are geared towards the libraries, national archives and science facilities sectors. There are four main LTDP cost models which are namely NASA's cost estimation tool (CET) (Hendley 1998), Lifecycle Information for E-Literature (LIFE) (Wheatley et al 2009), Cost Model for Digital Preservation (CMDP) (Kejser et al 2011) and lastly, Keeping Research Data Safe (KRDS) (Stanger 2011).

NASA CET is focused on targeting the scientific sector. It was designed to estimate the lifecycle costs involved in maintaining and managing data centres. The tool is based on historical data and based on 'what-if' scenarios. Another cost model for LTDP is the LIFE project which consists of three phases, namely LIFE1, LIFE2 and LIFE3. The main target and focus of the LIFE project is to serve the library and heritage sectors. The LIFE cost model focuses on examining file complexity and it depends mainly on the open archival information system (OAIS) standard model (CCSDS 2012) which is used to breakdown the cost.

KRDS LTDP cost model was developed to serve the science facilities sector. The model is similar to NASA CET and LIFE in that its data comes from multiple UK universities and a number of archives and projects. The cost model is used to assess a cost benefit analysis of preserved data. KRDS mainly integrates the best functions of the NASA CET and LIFE project. However, its limitations with the science facilities sector questions its applicability to other sectors. A limitation of KRDS is also that it fails to define the cost breakdown and its relation to the OAIS standard model (Stanger 2011).

CMDP was developed by the Danish National Archive and has two main phases. CMDP1 is focused on preservation planning and information migration while CMDP2 is focused solely on the ingest phase (CMDP 2010) and not the whole lifecycle cost. The cost model uses the activity based costing (ABC) approach and is closely related to the OAIS model.

The literature has highlighted that there have been many attempts to accurately estimate cost for LTDP activities. However, these attempts are mainly focused towards the scientific and heritage sectors. There is lack of research investigating the development of LTDP cost estimation systems for the financial, clinical trials and healthcare sectors. Thus, this research study presents the design and development of a cost engine system that is fully integrated into a large digital preservation system and aims to estimate the whole life cycle cost for preserving digital information using cloud computing for the aforementioned sectors.

3 ADOPTED RESEARCH METHODOLOGY

Due to the collaborative nature of the research study, a research methodology satisfying both industry and academia has been selected. Both qualitative and quantitative research approach has been used to design and develop the ENSURE cost engine system. An activity-based costing approach has been employed to design the software system. In the first phase of the research method, the identification of cost drivers and cost break down structures (CBS) was completed and validated with seven digital preservation experts using a series of interviews and discussions. Following on from this, over 40 equations and rules were derived representing costs of LTDP activities. The next phase was to design the system using the UML class diagram to represent cost objects in order to elicit cost metrics for each object. Attributes of each cost objects were represented followed by identifying the relationships between the cost objects. An architecture diagram was designed to represent how the cost engine interacts with the rest of the ENSURE system. This activity involved clearly identifying inputs from the ENSURE configurator and outputs of the cost engine system for LTDP activities. Furthermore, the service oriented architecture (SOA) approach was used to design the cost engine system as a web service in order to deploy its functions publicly and as an open-source technology. Lastly, the cost engine system business logic was implemented using the object oriented (OO) java programming language containing over 2000 lines of code-logic. The cost engine is now fully integrated as part of the ENSURE system and has been validated qualitatively through experts opinion. Quantitative

validation is underway and the cost engine system will be validated with experts and use-case partners within the financial, healthcare and clinical trials sector.

4 COST ENGINE EQUATIONS AND UML DESIGN FOR LTDP ACTIVITIES

Table 1 illustrates an example of some of the cost engine implemented equations. The cost represented in this equations are namely, data management fixity check cost, cloud storage cost, ingest cost and data protection encryption cost.

Table 1: Excerpts of Cost Engine Implemented Calculations

Cost Metric (€)	Cost Calculations	Description
Data Management Fixity Check Cost	$\left(\left(\text{storage volume (GB)} \div \text{fixity check processing rate} \left(\frac{\text{GB}}{\text{hr}} \right) \right) \times \text{processing cost} \left(\frac{\text{€}}{\text{hr}} \right) \right) \times \left(\text{frequency of checks} \left(\frac{\text{no}}{\text{year}} \right) \times \text{data retention period} \right)$	All costs incurred to carry out all fixity checks for a set of data for the retention period
Cloud storage cost	$\left(\text{storage volume (GB)} \times \text{volume price} \left(\frac{\text{€}}{\text{GB}} \right) \times \text{storage duration (month)} \right) + \left(\text{cost of requests (€)} \times \text{number (\#) of requests} \right)$	All costs incurred to store the files on the cloud storage system
Information Package Generation Cost	$\left(\text{storage volume (GB)} \div \text{ingest processing rate} \left(\frac{\text{GB}}{\text{hr}} \right) \right) \times \text{ingest processing cost} \left(\frac{\text{€}}{\text{hr}} \right)$	The cost incurred to generate the SIP (Submission Information Package)
Data Protection Encryption Cost	$\left(\text{storage volume (GB)} \div \text{encryption processing rate} \left(\frac{\text{GB}}{\text{hr}} \right) \right) \times \text{encryption processing cost} \left(\frac{\text{€}}{\text{hr}} \right)$	All costs incurred to carry out data protection actions on ingested files

Figure 2 illustrates the OOP UML cost engine design. The cost engine classes are defined by the core activities carried out in digital preservation. These are ingest, access, storage and data management activities. Transformation and staff costs are also included to cover a wider range of cost drivers. Furthermore, it has been identified that companies wishing to carry out digital preservation activities would like to know how much they need to invest initially to start up preservation activities. Thus, an initial investment cost object was developed in the cost engine model to describe non-recurring cost (e.g. virus software cost) and infrastructure cost (e.g. physical space cost, cooling cost for servers).

5 ENSURE COST ENGINE SYSTEM ARCHITECTURE

The cost engine system architecture is comprised of several communicating components that implement the overall ENSURE cost evaluation and optimisation system. Figure 3 illustrates the architecture of the cost engine and how its modules interact with the rest of the ENSURE system. The Global Preservation Plan (GPP) is passed from the configurator to the preservation plan optimiser (PPO) with a full set of parameters. The GPP is comprised of the preservation plan and preservation configuration. The preservation plan describes 3 main types of actions associated with digital preservation activities. These are: system actions which affect all aggregations within the preservation plan; aggregation actions which affect specific aggregations; and copy actions which affect only one copy of a specific aggregation (e.g. Rackspace EU copy for market data aggregation). Copy actions can often be described as primary and secondary storage actions. The preservation configuration describes the physical architecture, software and plugins employed for digital preservation activities. These plugin service instances are implicitly interconnected to the actions within a preservation plan via their plugin service instances id description.

The PPO is the master component which controls the cost engine component and manages its dialog with the Configurator. Within the cost engine architecture, the cost engine web service module describes and implements the cost engine business logic for both the evaluation and optimisation operations. The PPO provides the cost engine's input parameters via the configurator. The inputs

include the GPPs to be evaluated, a list of plugin service instances (PSI), requirement sets and user preferences.

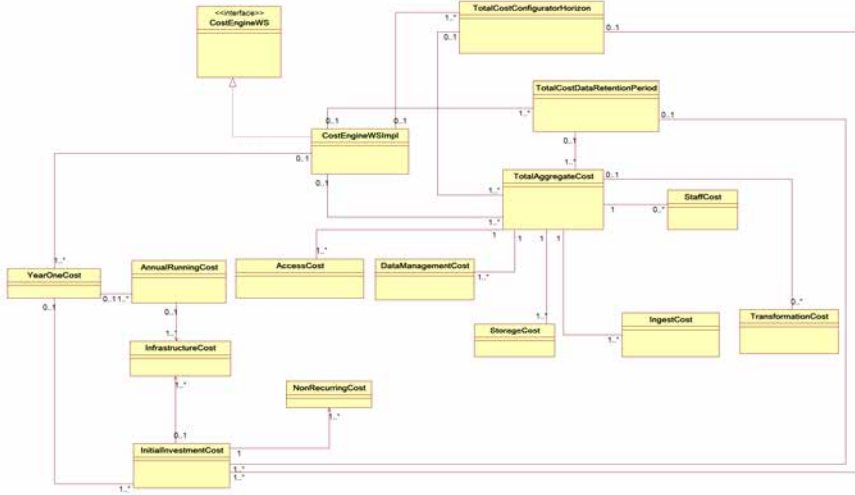


Figure 2: ENSURE UML Cost Engine Simplified Class Diagram

The data handler component manages the data flow between the configurator, the PPO and optimisation engines (i.e. cost engine, quality engine and economic performance engine). The output of the cost engine is converted into a set of java classes. These classes are pre-defined in the configurator and passed back to the PPO which then communicates the results to the end user through the ENSURE graphical user interface. The inputs and outputs of the configurator classes are explicitly integrated with the cost engine classes. Therefore, the cost engine model is translated to the configurator model to ensure common semantics between the overall ENSURE system. The Configurator Utilities library was used by the cost engine for testing and verifying the cost engine's business logic implementation. Furthermore, error handling was incorporated into the cost engine business logic in view of ensuring the security and integrity of the cost engine system.

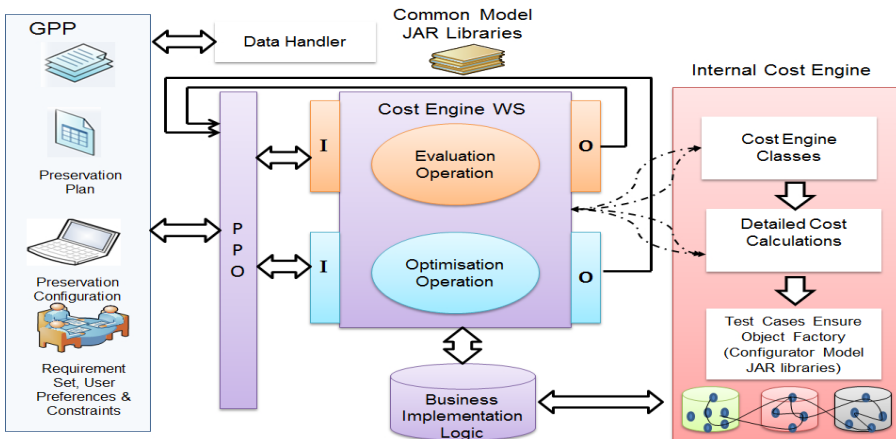


Figure 3: ENSURE Cost Engine Architecture Model Description

6 VALIDATION

The cost engine system has been validated qualitatively through experts' opinion. This has been achieved through various mediums such as discussions and weekly group meetings with the rest of the ENSURE consortium. The first phase of validation involved validating the equations and rules of the cost engine with the ENSURE consortium which involves 12 industrial partners from an IT, healthcare, clinical trials and financial industry. The second phase of validation involves the validation of the cost engine integration with the ENSURE configurator layer. Several test cases have been conducted which matches the expected outputs of the cost engine to its actual outputs. This includes verification of the cost engine business logic and the cost engine interfaces. Quantitative validation will commence which will focus on validating the cost metric numbers with real numeric numbers from the use-case companies (i.e. clinical trials, healthcare and financial). The quantitative validation will consist of several case studies with use-case partners and other digital preservation experts in order to ensure the applicability, validity and generalisability of the cost engine system.

7 CONCLUSIONS

This research paper has presented the design and development of a cost engine system for estimating the whole life cycle cost of LTDP activities for the finance, healthcare and clinical trials sector. The main cost drivers for LTDP activities have been identified and translated into a set of mathematical formulas to enable the accurate estimation of LTDP cost. The cost engine has been implemented using the object oriented approach and the Java programming language. Additionally, the service oriented architecture approach has been employed to develop the cost engine as a web service. The cost engine system is now fully integrated into the overall ENSURE system. The ENSURE configurator input is passed by the preservation plan optimizer to the cost engine input parameters. As a result of this, the cost engine calculations are executed which in turn outputs an estimated cost for LTDP activities for each candidate GPP. The benefit of the cost engine system is an accurate cost estimation for LTDP activities which companies belonging not only in the healthcare, clinical trials and financial sector but also manufacturing industries can use as a crucial decision support tool.

ACKNOWLEDGEMENTS

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AN INVESTIGATION INTO THE CLOUD MANUFACTURING BASED APPROACH TOWARDS GLOBAL HIGH VALUE MANUFACTURING FOR SMES

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ABSTRACT

Considering the high labour costs and intensive competitions in the global market, improving the effective deployment of innovative design and manufacturing and utilisation of all existing technical information, for the full life cycle of the product, is essential and much needed for manufacturing Small and Medium sized Enterprises (SMEs) in particular. Cloud Manufacturing, as a powerful tool supported with 'big data', will likely enable SMEs to move towards using dynamic scalability and 'free' available data resources in a virtual manner and to provide solution-based, value-added, digital-driven manufacturing service over the Internet. The research presented in this paper aims to develop a cloud manufacturing based approach towards value-added, knowledge/solution driven manufacturing for SMEs, where there are many constraints in engaging responsive high value manufacturing. The paper will present the framework, architecture and key moderator technologies for implementing cloud manufacturing and the associated application perspectives. The paper concludes with further discussion on the potential and application of the approach.

Keywords: Cloud manufacturing, Virtualised resources, Service-orientated manufacturing.

1 INTRODUCTION

In an era of globalisation, design and manufacturing of the product cause all manufacturing organisations to face issues such competition in market, emergence of new technologies, and better utilisation of existing resources. To deal with complexity in the manufacturing processes and manage the market diversity, manufacturing organisations try to develop and realise scalable integration of many kinds of manufacturing resources (Wu and Yang 2010). Managing and sharing manufacturing resources globally becomes more complicated due to their possession by geographically distributed enterprises (Tao *et al.* 2008).

Cloud computing, known as a powerful tool, indicates a main change in the way information technology (IT) services are invented, developed, scaled, deployed, updated, maintained and funded. Nowadays, computing power becomes an essential commodity as computers constantly become more important and the cost of per unit consumption of computing continues to drop quickly (Hackett 2008). Although computing continues to become more universal within the whole organisation, computing becomes more costly than ever before for an enterprise due to the growing complication in the management systems of the infrastructure of various information architectures and dispersed data software (Roehrig 2009). In fact, manufacturing SMEs now desire to employ 'pay per demand' methods, due to the lack of enough capital and human resources to own, develop, support, and maintain the computing resources. Therefore, cloud manufacturing is inspired by cloud computing technology to take some advantages, such as resource integration, resource sharing and collaboration among global enterprises.

The rest of the paper is organised as follows; Section 2 explains the concept of cloud manufacturing, Section 3 proposes a cloud-based manufacturing structure for SMEs. While Section 4

defines benefits and challenges of the proposed cloud manufacturing, some conclusions and future works will be considered in Section 5.

2 CONCEPTION OF CLOUD MANUFACTURING

Surviving in global manufacturing competition, manufacturing SMEs have to realise and deploy existing services, knowledge innovation, and scaling the customer requirement. However, different types of current manufacturing requirements cannot be covered and supported by existing advanced manufacturing models, such as Agile Manufacturing (AM) (Yusuf *et al.* 1999), application service of provider (ASP) (Factor 2003), networked manufacturing (NM) (Fan 2003), and Manufacturing Grid (MGrid) (Tao *et al.* 2010).

Table 1 provides some features of existing advanced manufacturing models, indicating the necessity of a new model to transform product-orientated manufacturing to a service-orientated manufacturing model. Hence, cloud manufacturing as a potential solution (CMfg) is suggested.

Table 1: Features of existing advanced manufacturing

	Advantage	Disadvantage
AM	<ul style="list-style-type: none"> • Design innovation based on the customer's requirement • Respond quickly to emerging crisis • Flexible organisation structure 	<ul style="list-style-type: none"> • Intensive planning and management of system • Shortage of proper platform supporting for resource sharing
NM based on ASP	<ul style="list-style-type: none"> • Provide leasing and management for software resource • Realising the platform of the resource and information sharing 	<ul style="list-style-type: none"> • Lack of sharing the hard resources and manufacturing capabilities
MGrid	<ul style="list-style-type: none"> • Sharing of distributed resources • Workforce development 	<ul style="list-style-type: none"> • Lack of proper operating business model

The core concept of cloud manufacturing, developed from employing service-orientated manufacturing model, advanced computing technologies, Internet of Things (IoT), and virtualisation, is based on enterprise information technologies and existing advanced manufacturing models (Tao *et al.* 2012). Therefore, cloud manufacturing provides the utilisation of manufacturing resources separated geographically but available globally through the internet, and facilitates a virtual manufacturing resource environment for both individuals and enterprises to share and integrate all resources.

Mainly, three layers of user participate in a cloud manufacturing platform, namely, manufacturing cloud, operator, and cloud customer (Fig.1).



Figure 1: Cloud manufacturing main layers

All manufacturing resources and capabilities are owned and provided by the manufacturing cloud. The operator facilitates the services for both the cloud customer and the manufacturing cloud through the cloud manufacturing platform. Hence, the cloud customer who is the subscriber of the services can take advantage of the 'on demand' or 'pay as you go' model.

3 THE CLOUD MANUFACTURING BASED APPROACH AND ITS IMPLEMENTATION ARCHITECTURE

As shown in Fig.2, the proposed architecture of the high value-added cloud manufacturing for SMEs is categorised into three main layers, Cloud Customer Layer, Operator Layer, and Manufacturing Cloud Layer, in which each layer includes some sub-layers. Moreover, there are three intermediate layers among the main layers, namely, transaction layer, business model layer, and basic supporting layer.

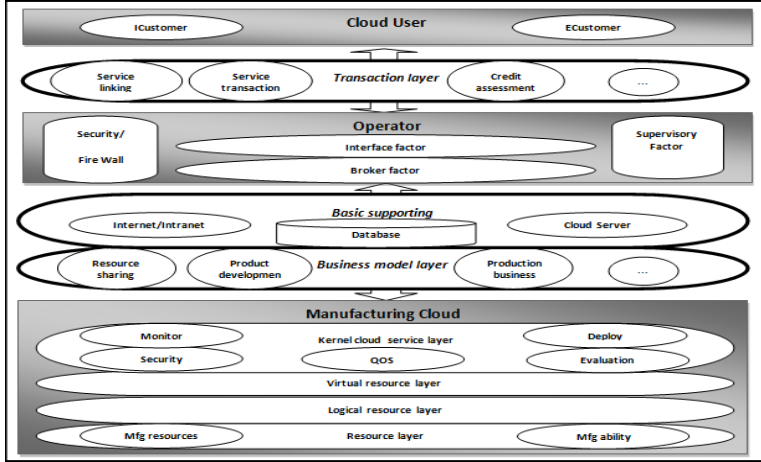


Figure 2: Cloud manufacturing platform

3.1 Cloud Customer Layer (Main Layer)

The cloud service users are the main layer which consists of two different types of consumer seeking to obtain the appropriate service (Fig.3): Individual customer (ICustomer) and Enterprise customer (ECustomer).

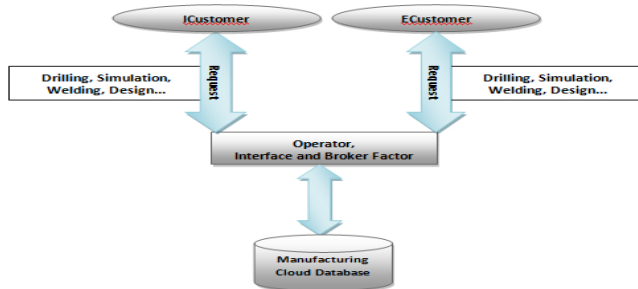


Figure 3: ICustomer/ECustomer

The former includes an individual customer or organisation based on the request of different ranges of self-contained operation activities for the entire production life cycle. All their requests are captured, analysed, and delivered by an interface factor, such as, drilling, simulation, welding, and design (Vincent and Xu 2013). Simply, the customer submits their request, the provider starts to search into

the manufacturing cloud database and allocates the best service for the customer, in terms of cost and time. The latter consist of enterprises that need extra manufacturing services and capabilities, for instance, customers requiring a unique or unusual service which the enterprise cannot perform itself. Therefore, the enterprise can obtain different, possible solutions suggested by the operator on the basis of factors, such as, cost, time, and quality.

3.2 Transaction Layer

The transaction layer is an intermediate layer which should facilitate all business related to the cloud manufacturing platform, such as, service linking, transaction services, and credit assessment.

3.3 Operator Layer (Main Layer)

The Operator layer is a main layer whose location is based on the intelligence factor. Complexity in manufacturing processes, different types of machines and devices, and geographical distribution of manufacturing resources make manufacturing decisions difficult (Xu 2012). Therefore, intelligence factor technology plays an important role in providing this layer. The Operator layer is categorised into three parts under firewall protection, namely interface, broker, and supervisory. An interface is responsible for communicating with a customer in order to help them in executing computational tasks (Laurel 1997). After collecting the customer request, the order is referred to the broker where availability of services are searched and evaluated in the manufacturing cloud database. The procedure from making requests to the final delivery of the services is shown in Fig.4:

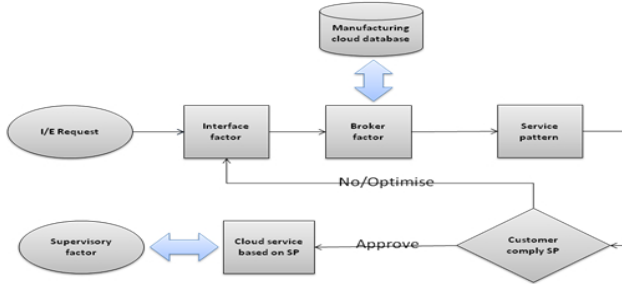


Figure 4: Request, discover and deliver process

1. Interface collects the request made by I/E Customer, transforms the demand into a standard template to make an related document, and finally refers to the broker.
2. Broker starts searching and providing the best solution into the manufacturing cloud database.
3. According to circumstances, such as time to make, time to delivery, cost, and quality, a primary service pattern is generated and returned to the I/E Costumer to be evaluated and modified.
4. Once the service pattern is approved by I/E Costumer, the designated cloud service is proceeded by the supervisory function that has the duty of supporting, monitoring, and controlling the entire functionality through the cloud service platform.

3.4 Basic Supporting Layer

The Basic supporting layer is an intermediate layer and consists of three sub-layers (cloud server, database, and network resource). This is covered by the Infrastructure as a Service equipment management model. In order to facilitate the basic operation support platform, the cloud server should have an efficient extensibility and the database should encompass different types of data format to simplify access by the operator (Huang *et al.* 2012). Furthermore, network resources should be located and defined in the cloud manufacturing platform to provide the communication environment three users' category.

3.5 Business Model Layer

The Business model layer is an intermediate layer providing related customer's business requirement. The Manufacturing cloud must provide the platform by realising and designing the functional business model layer to enable customers to match the best service model according to their requests.

3.6 Manufacturing Cloud (Main Layer)

The Manufacturing cloud layer is a main layer. As mentioned before, all manufacturing resources and their abilities are provided through the entire life-cycle of the production procedure. This layer categorised into four sub-layers, resource, logical resource, virtual resource, and kernel resource layers.

1. Resource Layer

The Resource layer includes manufacturing resources and manufacturing ability. The former one is defined as tangible and intangible, distributed, manufacturing material provided by dissimilar organisations such as machinery equipment, tools, and devices which exist in the soft resources and hard resources. While soft resources mainly covers software, data, employees, and skills, hardware consists of physical manufacturing sources such as manufacturing equipments, servers, computers, and materials. The latter one is defined as the ability to use all manufacturing sources through the manufacturing process, such as, design ability, management ability, and experimental ability.

2. Logical resource Layer

Directly managing and understanding the manufacturing resources and abilities are quite difficult processes for customers. The Logical resource layer causes physical services and capabilities to be more sensible and provides the connection platform into the network, internet, broadcasting, and the telecommunication networks.

3. Virtual resource layer

In this layer, all manufacturing resources and abilities are virtualised and encapsulated into the manufacturing cloud services. The main aim is to realise interoperable resource management by using different technologies, such as, IoT, Radio-Frequency Identification (RFID) and Global Positioning System (GPS).

4. Kernel cloud service layer

Cloud manufacturing has to provide the required tools for the three category users (that is, customer, operator, and provider) in order to monitor and manage the service platform through, for example, operation environment including security, evaluation, and quality of service (QoS).

4 BENEFITS AND CHALLENGES OF CLOUD MANUFACTURING PLATFORM

The Cloud manufacturing platform could offer some advantages to SMEs in terms of cost and time efficiency, management issues, agility, and customer centric issues. The following section will mention advantages and disadvantages of the service-orientated, cloud manufacturing paradigm.

Cloud manufacturing focuses on the importance of optimising resource utilisation and capacity in order to increasing manufacturing productivity. For instance, IT sources utilisation was less than 20 % through product-orientated manufacturing, while the service-orientated cloud manufacturing sector has improved the IT utilisation up to 40% (Rosenthal *et al.* 2009). Moreover, Cloud manufacturing allows globalisation which is the main aim of advanced manufacturing in the current era of communication. Easy access to virtualised and encapsulated manufacturing resources facilitate an agile environment via the internet and networks for both user and manufacturer.

Cloud-based manufacturing not only provides more business opportunities and adequacy by mixing products as a special offer to consumers, but also estimates and evaluates the customer demand, hence, scaling the manufacturing according to the customer needs.

Besides all its advantages, it could be argued that a cloud manufacturing platform faces certain challenges, for example, (1) safety and security issues, (2) shortage of certain standards, (3) effective extension of management and optimisation, and (4) existing unstructured data.

5 CONCLUSION

Moving from traditional product-orientated manufacturing to a service- orientated type provides new manufacturing solutions to achieve cost-effective, manufacturing systems. However, the research on cloud based manufacturing approach is still in its infancy and has a long way to go before it is adopted and perfectly executed. In this paper, first the background and concept of cloud manufacturing has been introduced, followed by an explanation of the proposed service-orientated, cloud-based, manufacturing structure, its benefits and its difficulties.

In order to practical executing the proposed architecture, the next step is to explain the efficient data models. For instance, STEP standard (Standard for the Exchange of Product model data) among the various proposed data models could be an appropriate solution.

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COST MODELLING FOR CLOUD COMPUTING UTILISATION IN LONG-TERM DIGITAL PRESERVATION

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ABSTRACT

The rapid increase in volume of digital information can cause concern among organisations regarding manageability, costs and security of their information in the long-term. As cloud computing technology is often used for digital preservation purposes and is still evolving, there is difficulty in determining its long-term costs. This paper presents the development of a generic cost model for public and private clouds utilisation in long-term digital preservation (LTDP), considering the impact of uncertainties and obsolescence issues. The cost model consists of rules and assumptions and was built using a combination of activity-based and parametric cost estimation techniques. After generation of cost breakdown structures for both clouds, uncertainties and obsolescence were categorised. To quantify impacts of uncertainties on cost, three-point estimate technique was employed and Monte Carlo simulation was applied to generate the probability distribution on each cost driver. A decision-support cost estimation tool with dashboard representation of results was developed.

Keywords: Cloud Computing, Cost Modelling, Uncertainties, Long-Term Digital Preservation.

1 INTRODUCTION

In current information society, the volume of digital information produced everyday has been increasing rapidly. As information is often required to be kept over a long period, there is a growing need of managing it to ensure its accessibility, sustainability and security over time. Cloud computing has emerged to organisations with a number of business benefits, e.g. cost saving, higher performance and increased availability. As the concept of cloud is relatively new, it is difficult to determine long-term costs of using this technology.

This paper presents the development of a cost model for cloud computing in utilisation of LTDP by including the impact of uncertainties and obsolescence issues on cost. The research study is part of the ENSURE project, a Seventh Framework Programme (FP7) project focused on providing a total solution for LTDP. The next section of the paper contains the literature review on areas related to the scope of the research. Section 3 describes an overview of the research methodology employed. Section 4 describes the main results of the research study: cost breakdown structure, uncertainties categorisation and costing and interactive cost modelling tool. In Section 5, the techniques that have been used to validate the research results are discussed.

2 RELATED RESEARCH

LTDP brings attention to storage and maintenance of digital information with the intention of accessing the content in the future regardless of any obsolescence in format, software and hardware (Factor, 2008). As digital information is fragile, vulnerable and susceptible to damage as it is created, used and stored (Waugh et al., 2000), it can be lost due to inability to access stored data and loss in quality or technical failures. The most common digital preservation techniques are migration, emulation, encapsulation and museum (K. Ho lee et al., 2002).

Cloud computing has been defined by the National Institute of Standard and Technology (NIST) as a “*model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction*” (Mell and Grance, 2011).

Uncertainty described as a state of inability to specify an outcome or event with certainty affects costs, technical performance and operation processes in current environment of rapid changing technologies in aspect of cloud computing (Erkoyuncu, 2011). The changes occurred in technology, economy, needs, demands lead to better understanding and detailed study of these uncertainties (MacManus and Hastings, 2006). Obsolescence is the process of becoming out of support or end of life, e.g. when product or service is no longer supported by original manufacturer (Dowling, 2004). Refreshing is one of the digital preservation techniques to keep the infrastructure up-to-date with most recent technology. This can be used to prevent obsolescence and failure of infrastructure components (Barateiro et al., 2010).

It is worth to mention that none of current cost models is focused on LTDP activities in cloud computing technology, which is essential since as a long term process, LTDP is especially subject to a number of uncertainties and obsolescence issues that can occur over time and have an impact on cost. Therefore, there is an apparent lack of a reliable tool capable of estimating and comparing costs for many deployment models, which would be useful for manufacturing industry planning to move into the cloud. This research study has made crucial findings on the costing of uncertainties and obsolescence issues on cloud computing for LTDP activities and development of cost model using combination of activity and parametric cost estimation technique.

3 RESEARCH METHODOLOGY

The challenge of developing a cost model for cloud computing utilisation in LTDP with consideration the impact of uncertainties and obsolescence issues, lies in the need of a consistent and rigorous methodology. The structured sequence of procedures and practices has the purpose of filling the previously described knowledge gap in related research. The adopted research methodology aims at successful and efficient development of the cost model for public and private clouds. Figure 1 illustrates three phases of this methodology: generation of cost breakdown structures, categorisation of uncertainties and obsolescence, development of cost model and Monte Carlo simulation.

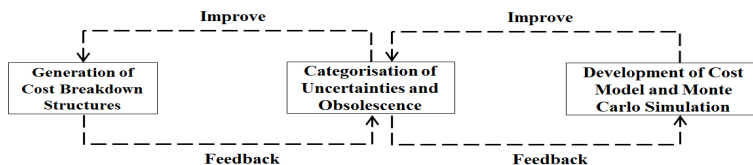


Figure 1: Research Methodology

To start with Phase 1, a number of interviews were conducted with wide range of industries, and then cost drivers were identified as consequences of the analysis of knowledge captured. The cost breakdown structures for public and private clouds were generated and validated by industry experts. Uncertainties and obsolescence issues were explored and categorised into high level classification from both cloud service provider and end-user perspectives. Phase 3 was carried out for the development of cost model. As a result of knowledge gained from phases 1 and 2, the cost model consisting of parameters, equations, rules and assumptions was built using a combination of activity-

based and parametric cost estimation techniques; therefore it can be called a hybrid cost model. The impact of categorised uncertainties and obsolescence was assessed, and three-point estimation technique was employed. Then, Monte Carlo simulation was constructed to illustrate probability distribution of future costs. Finally, the cost estimation tool with front-end graphical user interface and a dashboard representation was developed to support decision making on preserving digital information for public and private cloud.

4 RESULTS

4.1 Cost Breakdown Structures

The cost breakdown structure (CBS) for public cloud is presented in Figure 2. It consists mostly of service charges paid to CSPs and other operational costs.

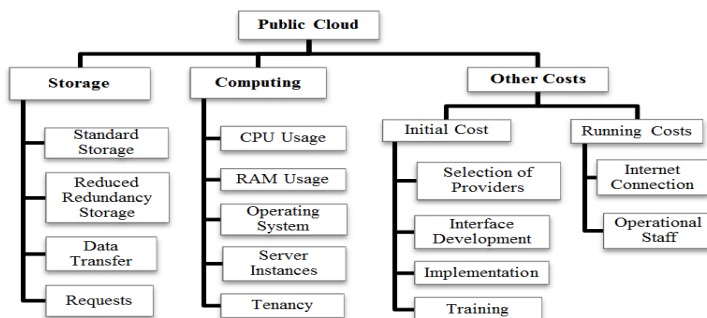


Figure 2: Cost Breakdown Structure for Public Cloud

The two main costs of public cloud utilisation have been identified as storage cost and computing cost. The standard storage cost depends on the exact volume of monthly used storage (in gigabytes). Other elements of the storage cost are size of monthly data transfer and number of requests sent to the cloud. Total computing cost is determined by a number of utilised server instances and their monthly utilisation in hours. The other running costs of public cloud utilisation are broadband connection cost and operational staff cost. As for the initial investment cost, there can be certain initial costs related to selection of providers and services that will fit the organisational requirements, the development and implementation of interfaces and ensure that employees are properly trained to work with cloud technology.

The cost breakdown structure for private cloud is presented Figure 3. The high level breakdown of cost drivers is categorised into acquisition, implementation, running, and redundancy costs.

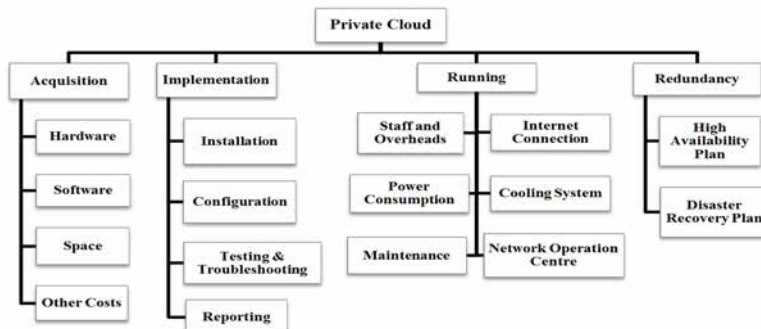


Figure 3: Cost Breakdown Structure for Private Cloud

The acquisition costs are composed of tangible and intangible assets that organisations purchase. These assets are composed of infrastructure such as hardware, software, space, and other costs e.g. power distribution system, cooling system, generator, fire protection, security facilities etc. Second category is implementation costs such as installation, configuration, testing, troubleshooting and reporting costs which depends on the size of data centre and number of labour required. Running (recurring) costs include a number of fixed costs, i.e. monthly operational staff costs and broadband connection cost, as well as variable costs, e.g. cost of power consumed by devices, cooling infrastructure, Network Operation Centre (NOC) and maintenance. Finally, redundancy cost is divided into two parts: high availability plan and disaster recovery plan. Both require acquisition and implementation of backups which are used to reduce downtime of system or to ensure that the system can be restored with best effort without any loss of data in case of any disaster. The amount of redundant infrastructure depends on company's policies. Redundancy plan involves also an additional cost of regular data transfer between primary and redundant systems.

4.2 Categorisation of Uncertainties in Cloud Computing

During deployment of both public and private clouds, there are uncertainties that have minor and major impact on cost, technical performance and operation processes. According to conducted interviews carried out along this research study, the identified uncertainties are classified into five categories: business, economic, regulatory, technological, and physical uncertainties.

Business uncertainties discuss the relationship between organisations and their behaviours. These behaviours relate to unknown situations that both cloud service provider and end user could experience. Business uncertainties can be broken down into four areas such as cloud service provider existence in the future, organisational culture, market trends, and business growth. Economic uncertainties highlights the importance of the economic state of a nation, country, or organisation and their effects on costs. Economic uncertainties can be broken down into inflation, energy prices (e.g. electricity and currency fluctuation if organisation operates in different regions or countries). Regulatory uncertainties interact with governmental and organisation policies, legislation, and standards. Additionally, any changes within the industry standards on digital preservation in cloud and international trade tariffs will have impact on cost. Technological uncertainties relate to the availability, elasticity of infrastructure, data representation (image, text or numeric), and the possibility of new technology. These can be divided into technology evolution, data format, data security, and obsolescence of hardware, software, people's skills and preservation plans. Physical uncertainties relate to tangible and intangible geographical elements, processes that have impact on costs e.g. natural disasters, climate changes, and solar occurrence. These uncertainties have lower chance of occurrence, however potentially high impact on cost if they do.

4.3 Costing Uncertainties and Monte Carlo Simulation

After categorisation of uncertainties, three-point estimation technique was employed for embedding impact of uncertainties into the cost model. Firstly, the maturity level of project definition was analysed based on the framework developed by Association of Advancement for Cost Engineering International (AACEI). Based on the user's input into the cost estimation tool, expected accuracy range is applied for best-case estimate and worst-case estimate. When the best-case, worst-case and most likely estimate values have been identified for each cost driver, Monte Carlo simulation for probability distribution is applied on these three value ranges. The results is displayed in a dashboard representation in order to view cost trends and select specific costs on specific years to support decision making.

4.4 Cost Modelling Tool

The cost modelling tool, which has been developed using Microsoft Excel and Visual Basic for Applications, is a software implementation of public and private cloud cost model. The tool consists of a number of modules. First, the user has to enter all their preservation requirements, which are needed to run the cost modelling calculations, using an interactive input interface. The calculated

costs are then presented in two different worksheets, which are dashboard representation and detailed text representation. The elements of the Dashboard interface are presented in Figure 4.

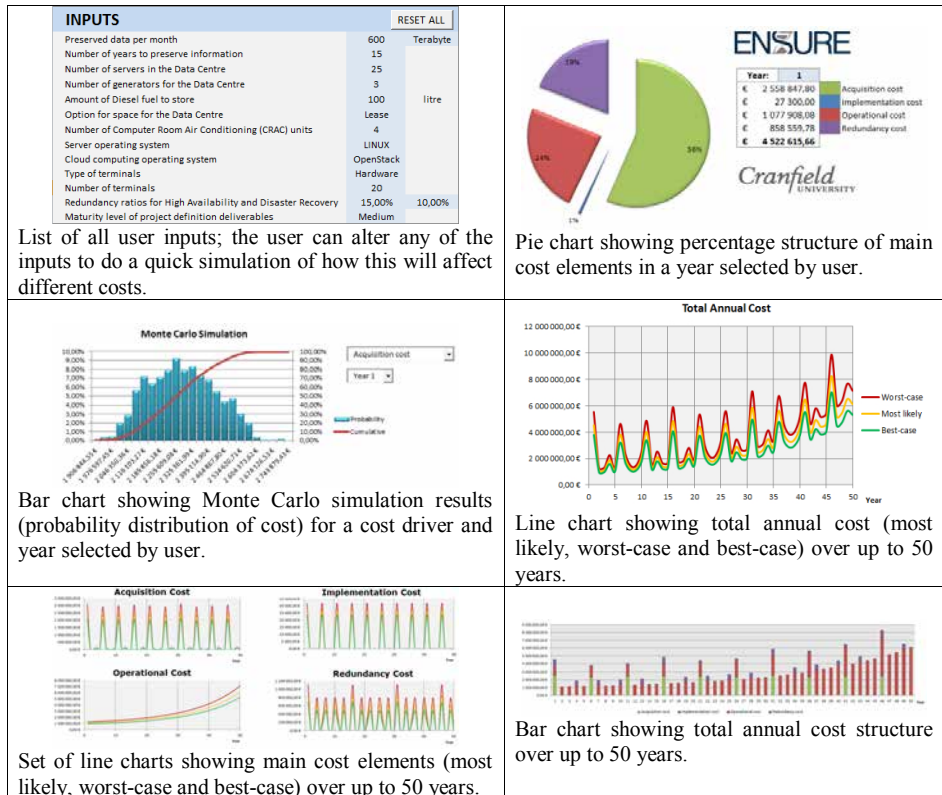


Figure 4: Overview of the Dashboard Elements

Apart from the charts, users can also see a detailed table of all costs with sub-totals and the total annual cost for every year in the detailed annual cost worksheet. In addition to the most likely cost values, the best-case and worst-case values are also provided for each high-level cost.

All parameters for cost modelling calculations (e.g. unit costs) are located in the public cloud and private cloud parameter worksheets, which are hidden for the users. There is also a separate Monte Carlo hidden worksheet, in which the random cost samples needed for Monte Carlo simulation are generated and the Monte Carlo charts are constructed.

5 VALIDATION

All results, methods and techniques employed throughout the research were validated in order to make the outcomes of the research credible. Validation process was continuous and lasted through all three phases of the research. The validation activities were based on a number of interviews and meetings with digital preservation and cloud computing experts. Every interview provided expert feedback on previously obtained research results and improved knowledge. The results of the interviews were systematically analysed and the outcomes of this analysis were used to revise and improve the deliverables. At the end of the last phase of the research study, the developed cost modelling tool for public and private cloud was validated by the ENSURE consortium members in a series of presentation sessions.

6 CONCLUSIONS

The research described within this paper focused on development of a generic cost model for cloud computing utilisation in LTDP. Its main tangible result is an innovative cost estimation tool, which is easy to use and does not require users to have a wide technical knowledge about cloud implementation. Therefore, it may serve as a decision-support tool, not just a cost calculation tool.

Long-term cost modelling for cloud computing is challenging, since it is very difficult to predict many long-term trends, e.g. prices of hardware, as not enough historical data is available. However, by using three-point estimation and Monte Carlo simulation, the developed tool returns a range of possible costs instead of a single point value, which provides the users with a realistic cost estimation.

The conducted research resulted in crucial addition to knowledge for cloud deployment costs, especially identification of detailed cost breakdown structure for private cloud. Private cloud requires high initial investment cost for purchase of infrastructure. However, the return on investment can be economically viable. Public cloud is a cost effective solution, not requiring organisations to make any considerable investments in advance. However, security and control of data becomes an issue.

There are diverse categories of uncertainties and obsolescence issues that should be identified and carefully considered while estimating costs of cloud deployment. The research provides classification of these issues, as well as an attempt to quantify their impact on cost and include it in the cost model.

In manufacturing industry, there are numerous uncertainties and obsolescence issues in long-term that have major and minor impact on cost. This generic cost model developed within this research can be employed for manufacturing, service delivery etc. industries as a decision-supporting cost estimation tool.

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STRATEGIES FOR IMPLEMENTING ACTIVITY-BASED COSTING IN THE UK MANUFACTURING INDUSTRY

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ABSTRACT

The purpose of this paper is to report the findings with a case study on why *activity based costing* lacks impact in the UK manufacturing industry. *Activity based costing* was performed on selected MT range subsystems of an electrical power generator to compare with the current UNN UK's conventional costing system. The results have found that the current costing system works well for the MT products and thus change of costing system is not necessary for these products. The *activity based costing* system can be partially implemented in UNN UK for areas requiring detailed costing information such as new renewable products. Based on the result of the case study, this paper also highlights the strategies need to be considered in order to adopt *activity based costing* within a typical manufacturing environment.

Keywords: Activity Based Costing, Conventional Costing Method, Strategies of implementing ABC in the manufacturing industry.

1 INTRODUCTION

Managers in many organisations have found that traditional costing methods are no longer able to cope with the change in information required by company management. Many companies found that traditional accounting methods were "too late, too aggregated and too distorted" to support decision making in costing (Spedding and Sun, 1999). Although the potential benefits of Activity Based Costing (ABC) systems were widely discussed (Bharara and Lee, 1996; Rezaiea et al, 2008), interestingly, the overall adoption rate of ABC system in UK is relatively low (Askarany and Yazdifar, 2012). This issue led researchers into investigation for the reasons of low adoption rate. One possible cause could be the contingency factors where the organisation characteristics might affect the adoption decision of ABC. This alone is not sufficient to explain the low adoption rate of the ABC system. Implementation issues such as technical and non-technical factors could also affect the decision for implementing the ABC system. Therefore, the focus of this paper is to demonstrate and discusses the differences between the ABC and Standard Costing methods using a case study approach.

2 FACTORS AFFECTING ABC IMPLEMENTATION IN MANUFACTURING INDUSTRY

The common factors affecting the adoption of an ABC system can be categorised into (i) contingency factors and (ii) technical factors (Chenhall, 2003; Fei and Isa, 2010a).

2.1 Contingency factors

There are a small percentage of organisations have adopted ABC in the UK. A possible explanation for this can be related to the contingency theory. According to (Chenhall, 2003), in this theory, an or-

organisational design depends on contingency factors such as environmental uncertainty and organisational size. The theory has been widely applied in managing costing system design (Chenhall, 2003; Fei and Isa, 2010b). Chenhall (2003) claimed that top management was unlikely to adopt costing systems that did not help to improve performance. Looking from the perspective of contingency theory, adoption of ABC in organisations depends on particular factors or variable of the organisation, and these can be categorised as contingency factors and technical factors. In general, the contingency factors consist of (i) organisation size, (ii) type of competition, (iii) product complexity and diversity, (iv) organisation strategy, (v) organisation structure, (vi) organisation culture and (vii) national culture while the implementation issues include (a) technical factors, (b) top management support, (c) organisation internal politics and (d) economic rationale.

2.2 Technical factors

During the early research on success factors of ABC implementation, researchers believed that the barriers and difficulties for ABC implementation were primarily due to the technical factors (Anderson, 1995). According to authors Cohen et al, (2005), Sartorius et al, (2007) and Fei and Isa (2010a, 2010b), these technical difficulties include:

- | | |
|-------------------------------------|--------------------------------------|
| (i) defining the scope of the model | (ii) identifying the main activities |
| (iii) cost drivers selection | (iv) problems in gathering cost data |

In addition, there are strong evidences suggested that failure in ABC implementation could be related to lack of support from top management (Anderson et al, 2002). Brown et al, (2004) explained that support from top management could reduce the level of uncertainty of the project as access to resources would become available and management of barriers across organisational boundaries would also increase, making the adoption of ABC easier.

3 IMPLEMENTING THE CASE STUDY

Top management usually considers implementing ABC for the following reasons: (i) increase competition in the market place, (ii) the need to reduce production cost, increase overhead activities and overhead costs, (iii) changes in the nature of product cost and structure of overhead cost. Nevertheless, the contingency factors alone are insufficient for explaining all factors that affect the adoption of ABC. The implementation issues should also be taken into consideration. These include technical difficulties, lack of top management support, organisational internal politics and economical rationale.

3.1 The Case study

MT Range products in power generator (MT11 and MT18) were selected for ABC calculation and synthetic data were used in the case study to protect confidentiality. In this case study, ABC calculation was computed for comparison against the conventional costing method used by UNN UK. The most common product within the ranges of MT11 and MT18 was determined to represent the MT11 and MT18 products. They were MT114E1 and MT1184E1. According to Innes et al (2000), there are four major steps in the application of ABC.

- **Identify the main activities**

Kaplan and Anderson (2004) suggested the major approach for identifying main activities is to prepare a standard activity dictionary which would captures and lists all activities performed within an organisation.

- **Cost the activities**

After the process of identifying activities, costing the activities is the next task. For activities requiring machining, they were usually monitored by the number of machine use per hour. If these could not be monitored, an estimate from a well knowledgeable employee would be used. For activities sharing a common resource, the cost would be apportioned according to the extent of use. As UNN UK produces a wide range of products, some of the activities in the MT range share the same resources with other products. Among all the activities identified, resources for MT Rotor, MT Stator and MT Assembly were not shared. However, other activities were sharing the same resources and expenses with other products. Thus, estimated percentages from the overall overhead costs were used for assigning costs to the activities in those departments.

- **Select cost drivers**

Lee and Kao (2001) defined cost drivers as factors that drove the cost of operational activities. Cost driver could also be defined as a variable which is a denominator in the rates when applying activity cost to products .

- **Apply cost driver rates to products**

Finally, the cost driver rate for each activity is multiplied to the volume of cost driver units consumed by each activity. The total overhead cost for both MT 11 and MT 18 products are shown in Table 1.

Table 1: Total overhead cost

Activities (MT)	Cost Drivers (MT)	Cost Driver Rate	Annual Driver Volume		Total overhead costs	
			MT11	MT18	MT11	MT18
Contract preparation	Number of product orders	1.50	3,000	5,000	4,500	7,500
Material handling	Number of work hours	1.80	2,000	3,000	3,600	5,400
Storage	Storage size (square meter)	3.29	1,500	2,000	4,929	6,571
Engineering process (MT Rotor)	Number of machine hours	9.98	5,000	10,000	49,897	99,794
Engineering process (MT Stator)	Number of machine hours	8.12	5,000	12,000	40,598	97,434
Engineering process (MT Assembly)	Number of machine hours	15.92	5,000	10,000	79,577	159,155
Quality Assurance	Number of inspection and test				102,557	158,964
Logistic	Number of product orders	25.45	2,000	3,500	50,909	89,091
Maintenance	Number of maintenance work orders				242,851	376,420
Warehousing	Space size	11.20	1,000	2,000	11,200	22,400
Training	Number of training				2,580	3,998
Total					593,197	1,026,727

The overhead cost for both MT 11 and MT 18 was calculated as shown in Table 2 (a). The total production cost for both products are shown in Table 2 (b). The formula for calculating the unit production overhead is shown as follow:

$$\text{Unit Production Overhead} = \frac{\text{Annual Overhead Cost}}{\text{Annual Production of Mach}} \quad (1)$$

Table 2: (a) Unit production overhead; (b) Unit production cost

				MT11 (£)	MT18 (£)	
	Annual Production of Machines	Annual Overhead Cost (£)	Unit Production Overhead (£)	Direct Material	500	850
MT11	3,000	593,197	197.73	Direct Labour	100	150
MT18	5,000	1,026,727	205.35	Production Overhead	197.73	205.35
				Total unit cost	797.73	1205.35

3.2 Comparison of ABC and Standard Costing methods

Table 3 compares the overhead and production costs between the ABC and Standard Costing systems. The overhead costs for MT 11 and MT18 are calculated by ABC which are 6.41% higher and 2.5% lower compared to those calculated on the standard costing system.

Table 3: Unit overhead and production costs

	MT11 Overhead Cost (£)	MT18 Overhead Cost (£)	MT11 Unit production cost (£)	MT18 Unit production cost (£)
Standard Costing System	185.1	210.6	784.20	1211.40
Activity Based Costing	197.73	205.35	797.73	1205.35

The differences in unit production cost between the two costing methods for MT11 and MT18 are 1.7% higher and 0.5% lower respectively. The results from both costing methods are generally very similar and there is no significant difference in the unit production costs between both costing methods. Figure 1 shows the annual production cost for both MT11 and MT18. The ABC system has demonstrated an ‘under-costing’ of £ 40,590 for MT11 and an ‘over-costing’ of £ 30,250 for MT18.

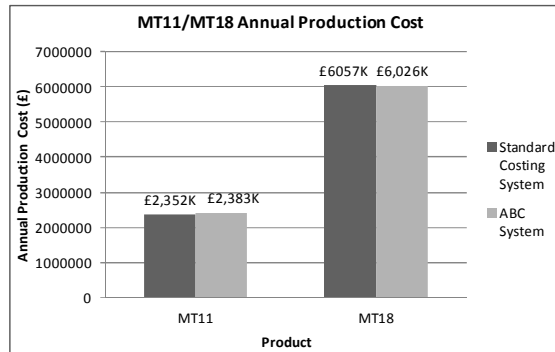


Figure 1: Annual production costs

3.3 Case Study Findings

- The application of the ABC system has reassured the appropriateness of using the Standard Costing system in UNN UK.
- ABC system provides a better visibility and insight which allows the UNN UK top management to monitor the company's process and activity costs.
- The information acquired from the ABC calculation also helps the top management to identify potential cost reduction opportunities to improve decision making.

4 RECOMMENDED STRATEGIES FOR IMPLEMENTING ABC

- Changes will have an impact on most employees. Strong and valid rationale is required to convince all employees to accept the change. This can be related to the national culture of low power-distance and individualism in the UK.
- Communication to all levels of employees is very important and their opinions have to be taken into account. This increases the difficulties for implementing a change. Ineffective communication among all levels of employees may lead to organisation internal politics. Employees may resist changing when they are in doubts of the intention of the change.
- Major technical issues for adopting ABC include:
 - Compatibility with the current manufacturing system and IT infrastructures.
 - The complexity of ABC system
 - Difficulties in identifying the main activities, cost drivers and challenges for costing the activities accurately.

In addition, ABC system consumes more time in data collection and interpretation and this may delay the decision making. Compared to ABC system, Standard Costing system is a simpler method that provides valuable information in a shorter time.

- (iv) High level of commitments from all levels of employees is necessary to successfully implement the ABC system. The affordability for all resources to implement ABC is also an issue itself. UNN's organisation culture of "attention to detail" in preference to "innovation" implies the less likelihood for ABC Implementation.

Overall, the results from ABC calculation have confirmed that the Standard Costing system in UNN works well for MT11 and MT18 products. This relieves the doubt about the accuracy of overhead cost for these two products. ABC system can be partly implemented to complement the Standard Costing system particularly in the areas requiring detailed information such as new products development for gaining better appreciation and more benefits to the business.

5 CONCLUSIONS AND FURTHER WORK

One of the main reasons that ABC system has not been adopted in UNN is the lack of interest for the ABC system by the top management. The Standard Costing system works well for the size of this company because most products are manufactured in similar ways. The current system is capable of providing valuable information for competing in quality and services because the main costs are material costs (copper and steel).

Recommendations for further work, for example:

- Perform ABC calculation for all ranges of products, especially new emerging products to better understand the cost structure.
- Manually identify the cost drivers which are not available from the current costing system
- Increase the sample size of the questionnaires to include more departmental managers as well as lower level employees within the company.

Both the contingency factors and implementation issues are under investigation involves collaboration with a global leading power generator manufacturer, UNN UK. The study attempts to explore in depth the factors that affect the decision for implementing the ABC system against the conventional costing system (Standard Costing) through conducting questionnaires and semi-structure interviews with six key stakeholders within UNN.

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COST, BENEFIT, AND FINANCIAL RISK (COBEFR) OF ERP IMPLEMENTATION

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ABSTRACT

The purpose of this research is to develop Benefits, Costs, and Financial Risks (CoBeFR) model to show and measure the impact of ERP related decisions, such as degree of business process re-engineering and the level of hardware investment, on the organisational financial value (OFV). OFV is based on current time value of money (i.e. interest rate), financial risk, and net cash flows emerged from ERP system. Financial risk, the sensitivity of the organisation net profit to changes in market conditions, is affected by organisational adoption of ERP system. The main conclusion is that there are interrelated impacts of ERP implementation decisions to the organisational financial value. Therefore, decision maker should look at the implementation decision from a new perspective which is Organisational Financial Value (OFV) perspective

Keywords: ERP, Cost, Benefit, Financial Risks.

1 INTRODUCTION

Since ERP is an integrated set of systems across the organisation, it is expected to have an impact on organisation (Hendricks et al., 2007). Benefits could be tangible, in monetary terms, such as increasing sales and decreasing cost or intangible, in non-monetary terms, such as improved customer satisfaction and improved internal processes (Murphy and Simon, 2002).

ERP system costs millions of pounds in its implementation in consulting, training, buying licenses, business process re-engineering, and software development (Daneva and Wieringa, 2008). Logically, these costs should be rationalized to get support from top management (Murphy and Simon, 2002). Furthermore, ERP has its risks on organisation. Since ERP implementation is a radical transformation and integration of organisation's business practices, failure in implementing ERP could push the organisation out of business (Davenport, 1998). Consequently, the decision related to ERP implementation should not only consider the expected benefits of it but also it should consider its costs and risks.

To combine benefits, costs, and financial risks of ERP implementation, it is proposed to use Net Present Value (NPV) approach. Net Present Value approach is, in itself, not new and it is the most common technique for evaluating ERP systems (Morgan, 2005; Wu et al., 2008). Net Present Value is a ubiquitous technique in valuing assets, determining the fair price of it, based on expected cash flows that are discounted by the required rate of return (Gitman and Zutter, 2012; Rosacker and Olson, 2008). Required rate of return is misunderstood for the current practitioners. It is translated in their minds as the time value of money or the interest on money borrowed. Accordingly, NPV will not be able to address the risk factor (Pindyck, 1993).

This study has used the traditional approach for valuing ERP projects but with using the required rate of return defined by Sharpe (1964). According to Sharpe (1964), the required rate of return from an asset is based on three factors: the free risk rate (time value of money or interest rate), the sensitivity of the earning of this asset to the market conditions (the volatility of the net income), and the market risk premium (the motivation to invest in the current conditions of the market). By this way, risks of ERP projects are integrated in the evaluation process by measuring the impact of ERP implementation on the incremental firm Cash Flows (FCs) volatility. Other two factors, free risk rate

and market risk premium, are not controllable by decision maker but they can affect only the timing of investing in ERP project. At the end, this model could combine benefits, costs, and financial risks into a single equation to show how ERP project could affect the financial value of the organisation. In other words, this model could help us know how ERP can affect the cash flows of the firm across the time with considering the additional risk of implementing ERP.

2 LITERATURE REVIEW

There are different approaches used to evaluate IT Projects. They can be classified into a couple of groups (Rosacker and Olson, 2008): Financial and Economic approaches and Qualitative approaches. Qualitative Evaluation approaches focuses on qualitative models. These approaches are criticized because they mainly depend on ERP software and not on how benefits can be realized from it. Furthermore, these approaches cannot be easily understood by non-IT managers to evaluate ERP Investments (Morgan, 2005). Moreover, these approaches do not address the cost of implementing ERP in depth. As a result, this research will focus on Financial and Economic Models rather than the qualitative models. Financial numbers could be easily understood by top management (Morgan, 2005). In addition, financial numbers enable the top management to prioritize ERP project in the organisation across other projects. Moreover, the ability to evaluate ERP in dollars could make a sense for decision makers and portfolio managers. Consequently, this research will focus on financial and economic measures.

Financial and Economic models are based on financial criteria such as Cost Benefit Analysis, Budgetary Constraint, Payback, Internal Rate of Return (IRR) (Rosacker and Olson, 2008) and Valuation models (Pindyck, 1993). Although these models, except valuation modes, are valuable for managers because it translates the IT projects into monetary term, they do not provide any information regarding the timing of cash flows, financial risks, and project interdependencies. This research project will follow the financial and economic approach but with taking into consideration these missing points through using valuation models.

Information Economics, introduced by Parker and Benson (1987) to value IT Projects, is, basically, nothing but benefit/cost technique that takes into consideration the risk factor. Valuation models have two perspectives: Market reaction perspective (Ranganathan and Brown, 2006) and Fair Value perspective. Market reaction models are more based on the perceptions of investors in the market toward the Information Technology/ERP implementation announcements. Based on efficient market hypothesis, prices reflect the true value of the organisation based on the current available information (Fama et al., 1969). But this is not the case in the real life, stock prices do not necessary reflect the true value of the firm (Malkiel, 2003). Moreover, these models do not focus on the ERP project itself; rather, it focuses on the market condition and investors' perceptions. On contrary, this research focuses on what and how fair value of organisation changes because of taking different decisions in ERP implementation process. Therefore, this research comes to fulfil this research gap.

3 ERP LIFE CYCLE PERFORMANCE

ERP system is a new capability for an organisation to leverage its performance. Like any new IT capability embedded in the system (Thorp, 1998), ERP system decreases the organisational performance due to adaptation problems. According to thorp (1998), organisations need time to realize benefits from new IT capability. In the same vein, ERP system needs time for a full adaptation by the organisation.

As illustrated in **Figure 1**, after a decline in the organisational performance due to incorporating new ERP system, organisation commences to adapt to new system. Once resistance to change reaches to level 0, organisational performance increases until it achieves its targeted performance. Unfortunately, this process is not guaranteed; many organisations could not increase the performance and the performance keeps declining until facing organisational bankruptcy (Davenport, 1998). Therefore, many organisations adopted benefit realisation methodology to manage this process (Breese, 2012)

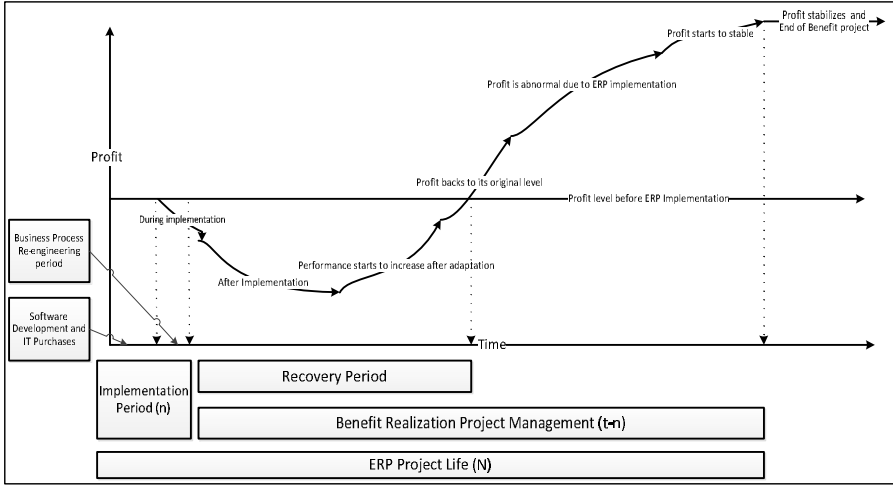


Figure 1: ERP Performance Lifecycle

4 COST, BENEFIT, AND FINANCIAL RISK (COBEFR) MODEL

4.1 Mathematical Representation of the model

Net Present Value (NPV) considers cash inflows, cash outflows, and cost of capital. The essence of NPV is the time value of money. One sterling pound today is higher in value than one sterling pound next year because this pound could be invested and get interest after one year. Using the same logic, one pound after one year should be discounted to get the value of it today. Since calculating the value in the future is by multiplying the current value by $(1+r)$, discounting the future value to get the value today will be by dividing the future value by $(1+r)$. Since this amount could be received after more than one year, and the interest is compounded, the present value today will be calculated by dividing the future sum by $(1+r)^n$ where (r) is the required rate of return and (n) is the number of years. Therefore, the equation will be

$$\text{Net Present Value} = \frac{\sum_{t=1}^N \frac{(BB_t - AC_t)}{(1+r_t)^{t-n}}}{(1+r_t)^n} - \sum_{n=1/12}^n \frac{(BPRI + SWI + HWI)}{(1+r_t)^{n/12}} \quad (4-1)$$

First, the Present Value of Net Annual Benefit

$$\frac{\sum_{t=1}^N \frac{(BB_t - SRC_t)}{(1+r_t)^{t-n}}}{(1+r_t)^n} \quad (4-2)$$

This is the operating net monetary benefit from the ERP but it is discounted by the required rate of return (r) to get the value of these benefits at the go – live phase.

BB_t: Business Benefits: it is the estimated monetary benefits in year (t) contingent upon the use of the new, or change in ERP

AC_t: Annual Cost: it is the expenditure in year (t) needed to run the new ERP services and includes hardware and software maintenance and support staff expenses. It is function of level of hardware purchases, number of modules, and level of customization.

(BB_t – SRC_t): it is the estimated Net Annual Benefit (NAB) in year (t)

t is the year of achieving the targeted benefit.

n is the number of years required for implementation

t-n is the incremental year number after the implementation date.

It is worth to notice that there are 3 stages: recovery stage, growth stage, and stability stage as illustrated in **Figure 1**.

$(1 + r_t)^{t-n}$ is the discounting factor of CF generated in time (t). However, this amount will come after go-live phase, which ends at year (n).

$(1 + r_t)^n$ is the discounting factor of the value of NABs at time (n) today.

r_t is the required rate of return at the year (t) from the IS project derived from Capital Asset Pricing Model (CAPM).

$$r_t = R_F + \beta \times (r_m - R_F) \quad (4-3)$$

R_F is the risk free return. It is the return that the firm can get from investing in risk free investment (e.g. bank interest rate for savers or treasury bills return)

r_m is the expected return from investing in the average stock market. This considers the current market condition.

$(r_m - R_F)$ is the market risk premium. In other words, how much incremental interest rate is required to motivate normal investor to invest in the market instead of in free risk financial instruments such as banks or treasury bills? This per cent is published in financial journals

β is the relative measure of risk. In other words, it is the new volatility of CF of the firm because of implementing the ERP project.

Second, the initial cost of acquiring/customizing the system

$$\sum_{m=12}^n \frac{(BPRI + SWI + HWI)}{(1 + r)^{m/12}} \quad (4-4)$$

BPRI: Business Process Re-engineering Investment: This cost includes the training cost, consultation fees, and below-average performance (as opportunity cost). It is based on complexity factors such as number of processes, number of people, level of IS readiness, learning curve of the people in the process, and the degree of change required.

SWI: Software Investment: Investments in Software are considered such as investment in software purchases, customization in system fees, training on the software, consultation fees, de-activating the old system, and system configuration expenses.

HWI: Hardware Investment: it is the funds required to invest in infrastructure and additional computers or hardware facilities. m is the number of months required to implement the project.

4.2 Graphical Representation of the model

Graphical representation of the model, as illustrated in Figure 2, describes the components of Net Present Value (NPV) of ERP project. NPV measures how ERP could increase the shareholders' wealth (Gitman and Zutter, 2012). NPV could be expressed as how much the firm could gain in money from the project after covering its initial and operating expenses and covering the cost of finance. As explained earlier, cost of finance depends on time value of money, market condition for investment, and relative financial risk of the project on the organisation's cash flow. Indeed, NPV consists of 3 components: Initial Cost, Net Annual Benefit (NAB), and Required Rate of Return.

Initial cost includes all initial cost required to implement ERP. This cost could be categorized into Software Investment (SWI), Business Process Re-engineering Investment (BPRI), and Hardware Investment (HWI). Software Investment (SWI), investments in purchasing; configuring; deploying; and training, is negatively correlated with Business Process Re-engineering investment (BPRI) (Fryling, 2010) because fewer changes in software will increase the investment in BPR to fit software with the organisation's processes (Brehm et al., 2001). Nevertheless, Hardware Investment (HWI) is assumed to be fixed and not to be subject to economies of scale due to ERP project size (Schwartz and Zozaya-Gorostiza, 2003). Since BPR could be used to minimize Hardware Investment, Hardware Investment is expected to be negatively related with BPRI. SWI and HWI are expected to have impact on annual maintenance cost because the more customization to the system, the more difficulty in maintaining it (Brehm et al., 2001; Fryling, 2010). Moreover, the more hardware used, the more the maintenance cost will be.

Operating Cash Inflow, or Net Annual Benefit (NAB), is the cash generated because of ERP project. As a result, NAB is monetary benefits realized after deducting annual maintenance cost. Actually, business benefits cannot be realized after completion, it takes at least two years to get what

is aimed to from it (Cline and Guynes, 2001). Logically, as illustrated in Figure 2, the performance, business benefits emerged from ERP system, will decline short after implementation, then it will increase across the time to a certain limit and finally stabilized at this level.

Cost of Capital, according to CAPM, consists of free risk interest rate, market rate, and financial risk of the project (Sharpe, 1964). Shareholders push board of directors to make a return on their investment at least equal to free risk interest rate (e.g. banks) adding to it the compensation for the additional relative risk of this investment to the firm current risk level (Gitman and Zutter, 2012). Although ERP project has many risks, financial risks only are considered. According to portfolio theory, the more you invest in divers assets the less the risks you care because if one asset increases the performance to abnormal level, the other asset will have a diverse effect. At the end, the sum effects of different assets are zero in terms of variations from the expected productivity. Consequently, the risks related to ERP project in itself is ignored because it will be compensated by other projects in the organisation or it will be compensated between subprojects in ERP. Nevertheless, ERP project has other type of risk, which is the financial risk.

Risk is a deviation from expectation. Consequently, the higher the deviation, the higher the risk will be. Based on this premise, if ERP project could affect the volatility of cash flow, it will have a financial risk. Volatility is a function of the leverage in organisation performance due to the new asset, ERP project. This leverage is expected because ERP project could increase the performance to abnormal level or decline it to abnormal level. This risk is very high at the beginning of the project but it starts to decline after that. Consequently, the financial risk should decline across the time followed by a decline in the cost of capital.

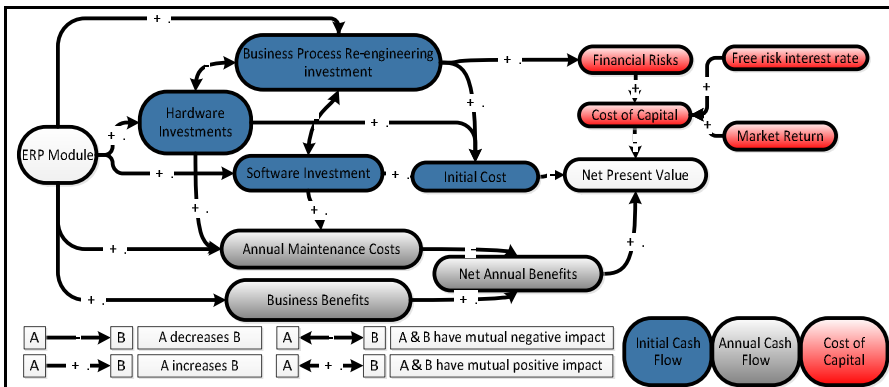


Figure 2: The CoBeFR Model

5 CONCLUSION

Since ERP is a huge project, its business case should be clearly stated. Traditional business case, which puts benefits and costs in a straightforward way, should consider the interrelationships between different cost components and their impacts on benefits emergence. Moreover, cost of finance, with taking into consideration financial risk, should be addressed in the planning process of ERP implementation. The CoBeFR model will help decision makers in identifying the relationships between costs, benefits, and financial risks to see the impact of ERP on the organisation value. The next step in this research is to start working in case studies to modify and enhance the model.

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TOWARDS A FRAMEWORK FOR PREDICTING WHOLE LIFE-CYCLE COST FOR LONG-TERM DIGITAL PRESERVATION

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ABSTRACT

Estimating the costs for the whole lifecycle of long-term digital preservation (LTDP) activities enables decision makers to choose carefully what data to preserve, duration of preservation and type of preservation techniques best applied for their information. To address this need, a framework is developed to generate a cost model that will estimate costs for long-term digital preservation activities using storage in the cloud and taking into consideration the impact of mitigating uncertainties, especially obsolescence issues on future costs. This cost estimating framework is part of the European project entitled 'Enabling kNowledge Sustainability Usability and Recovery for Economic value' which aims to provide a total long-term digital preservation solution for companies and public sector organisations interested in keeping their digital information alive for the long-term within the healthcare, financial and the clinical trials business sectors.

Keywords: Digital Preservation, Cloud Computing, Uncertainties, Obsolescence, Cost Estimation, Whole Lifecycle Cost, ENSURE.

1 INTRODUCTION

Digital data is now dominating the information scene (Charles Beagrie Limited, 2010); most of the currently generated information and records are in digital format or end up being digitized. This is due to the existence of new technologies and the ease of handling these digital data forms by the users (Hughes, 2004). In order to keep these vastly growing population of digital materials safe, useable, meaningful and accessible for a long period of time; preservation methods and techniques have been introduced and employed.

Enabling kNowledge Sustainability Usability and Recovery for Economic value (ENSURE) aims to provide a total long-term digital preservation solution for a new sector in the IT market. The businesses in healthcare, financial and clinical trials sectors are now interested to preserve their data, due to legal obligations and due to the increasing cost of data regeneration, especially in the clinical trials sector. Along with the new business sector, ENSURE is aiming to utilise cloud computing for storage and computing.

ENSURE aims to provide its customers from the three business sectors with a detailed cost and economic performance report. This will enable decision makers to select their long-term digital preservation requirements and have the highest quality preservation possible for the cheapest running cost and ensure ease of access to and security of data. ENSURE's cost model aims to tackle uncertain-

ties and obsolescence issues that may arise. This is due to IT systems that are prone to failures and obsolescence. Failures and obsolescence issues will generate cost to mitigate, and a rigorous study is needed to estimate the impact on future cost due to these mitigation strategies. To have a real cost estimate, that reflects the effect of uncertainties, ENSURE requires that the cost modelling development should include a thorough uncertainty study. It was identified by the authors that a contribution could be considered effective if a framework is generated, that when utilised can generate a cost model suitable for long-term digital preservation. This will benefit different business sectors and enable them to make better and accurate decisions about committing to any long-term digital preservation activity. This paper outlines an initial cost-estimating framework for LTDP in cloud computing and presents the results thus far.

2 COST MODELS FOR DIGITAL PRESERVATION

Many projects containing cost models to estimate costs of digital preservation exist for specific sectors, but most of them targets the libraries, national archives, representing the heritage sector and for laboratories and research facilities, representing science facilities sector. These projects have four main cost models, NASA's Cost Estimation Tool (CET) (Hendley, 1998), Lifecycle Information for E-Literature (LIFE) (Wheatley, et. al, 2009), Cost Model for Digital Preservation (CMDP) (Kejser, et. al, 2011) and Keeping Research Data Safe (KRDS) (Stanger, 2011).

CET is the oldest, targeting the scientific sector. It was developed to estimate lifecycle costs of maintaining scientific data centres. Its tool has a comparable database of historic data reachable through a set of what-if choices and parameter sensitive tests. CET has a strong cost model with comparable databases. This database started with 29 projects data, and the model is constantly updating and adding new ones to them. A highly recognised cost model that served the heritage sector is the LIFE project, which was developed by the cooperation of University of London and British library on three phases, LIFE1, LIFE2 and LIFE3. Its main target sector is to serve libraries. The LIFE cost model looks at the complexity of file formats which it divides into 10 separate complexity levels. LIFE depends hugely on the Open Archival Information System (OAIS) reference model (CCSD, 2002), which helps in breaking down the process levels.

Another cost model that was dedicated for the science facilities sector is KRDS, which was developed by the consultancy firm Charles Beagrie Ltd (Beagrie, 2008). The project finished in 2011, and its main concern is costing for research data preservation. Based on similar projects, CET and LIFE costs data collection from multiple UK universities and a number of projects and archives. The model analyses data and develops a cost benefit relation of preservation for given data sets. KRDS strong point is that it integrates the best of the LIFE and CET, where it gets the cost benefit and the lifecycle costing from. However, due to its limitation to the science facilities sector, the LIFE flexibility is lost. Another weakness in KRDS is that it fails to provide significant details in the activities based on the OAIS reference model, unlike LIFE and CET (Stanger, 2011).

The Danish National Archive developed in 2011 a cost model, focused on two main stages, CMDP1 and CMDP2. CMDP1 is for Preservation Planning and Digital Migration and CMDP2 is focused on the ingest phase (CMDP, 2010). The model is based on the OAIS reference model and uses the activity based modelling technique (Kejser, et. al, 2011).

The previous cost models have some weaknesses in common. Firstly, they do not have any uncertainties study integrated in their cost model, which questions the practicality of the model for the future. The second weakness is that they did not take in consideration cloud computing as a storage and computing option, which for the time being has high potential because of its ease of access, scalability and fast set-up time.

3 RESEARCH METHODOLOGY

To achieve the requirements and targets of the model, a research methodology was put in place to maximise the time dedicated for this project. Figure 1 shows the three main phases of the research methodology and related activities.

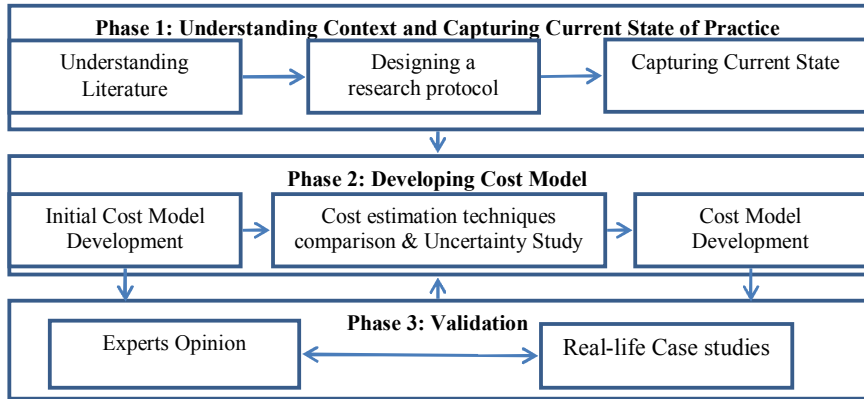


Figure 1: ENSURE Cost Model's Research Methodology (Badawy, M. et al. 2012)

Three main phases constructs the research methodology, phase one focuses on understanding state-of-the art of the science of digital preservation, cost modelling, and then capturing the current state of practice in the industry. The AS-IS model is captured using a surveying technique, in this case a questionnaire. Phase two initiates with developing an initial cost model that can represent costs for a single form of digital preservation, migration, as a starting point. Finally, phase three validates the developed cost model through experts' opinion and case studies.

4 LTDP COST PREDICTION FRAMEWORK DESIGN

The main target of this framework is to generate a cost model that can predict costs of carrying out LTDP activities in healthcare, financial and clinical trials business sectors, while considering the impact of uncertainties and obsolescence issues on estimated costs. The process of developing a framework for whole lifecycle cost of long-term digital preservation started with developing a framework to start the research with some viable information. This was followed by capturing LTDP activities for the ENSURE project. Capturing the use-case owners preservation requirements followed, a detailed Work Breakdown Structure (WBS) and Cost Breakdown Structure (CBS) of the ENSURE system and a complete Activity Based Costing (ABC) cost model was developed along with a cloud storage initial model. The cloud storage is now being expanded into a full cloud computing cost model with uncertainties and obsolescence impact on cloud computing utilisation costs, and when finished it will be implemented within the current cost model.

4.1 Framework

The framework design, as shown in Figure 2, is designed to study digital preservation whole lifecycle activities, and then generate a work breakdown structure of the current digital preservation activities. Afterwards it ensures that the activities are broken-down to their simplest forms and then chooses a suitable cost estimation technique to generate a cost model. Some rules are developed for the controlled behaviour of the model, then estimation and validation of the model is carried out through experts' opinions and case studies. After the validation process, any errors or deviations is fed into the design phase of the cost model generation to amend any known issues.

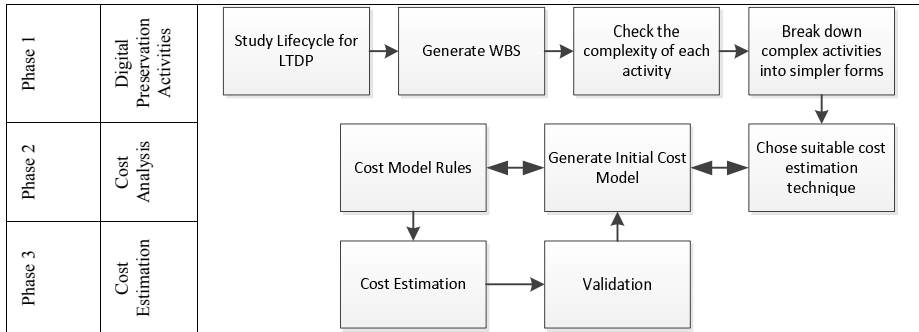


Figure 2: Initial Cost Estimating Framework for Long-Term Digital Preservation Activities

The framework was designed for the user to start with understanding the business requirements, followed by a work breakdown structure. Then studying the complexity of each work activity and make sure that it is represented in its simplest form; then from historical cost data present, the user selects a suitable cost modelling technique.

4.2 Lifecycle of Long-Term Digital Preservation

After the generation of the framework, it was essential to understand the whole lifecycle behaviour of the ENSURE preservation system, shown in Figure 3. This was achieved by carefully studying the ENSURE system requirements documents, attending the weekly system configuration meetings and carrying out two online workshops with consortium members.



Figure 3: Whole Lifecycle of LTDP

4.3 Sector Differences and Requirements

A series of interviews with use-case owners were conducted to capture their requirements for a digital preservation system. The focus was to find what is their expectation rather than their AS-IS situation. This is due to their lack of experience in the area. The main areas of differences were captured. The main areas of differences were in the preservation duration (i.e. data retention period), file types, file formats, their access rates to preserved files, copy rights issues and different legal requirements. These requirements affects the total cost of utilising the ENSURE system, for example, legal and copy rights issues will call for higher security, thus increase cost of encryption and decryption processing. Also higher access rates will generate a cost difference with relation to the storage facility used. And finally longer preservation periods will also result in an increase of incurred cost.

4.4 Work and Cost Breakdown Structure

The work breakdown structure, as illustrated in Figure 4, consists of five main areas that build together ENSURE preservation behaviour. In this WBS, Data Management is always active and continuously carrying out data checks to ensure the integrity and security of the preserved information.

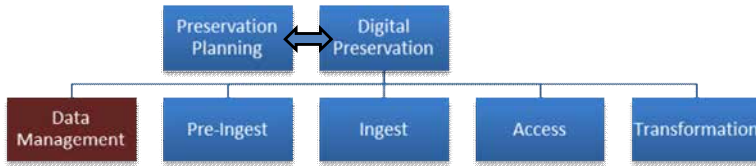


Figure 4: High-level View of LTDP WBS

The cost breakdown structure for the ENSURE system is presented in Figure 5 and shows a high level view of the cost generating activities. These activities' costs are calculated based on equations and rules. The expected outputs of the cost model are illustrated in Figure 5.



Figure 5: High level CBS for the ENSURE System

4.5 Activity Based Cost Model

The cost model has been developed into a detailed model based on the ABC estimation technique. This is part of the final expected cost model, when combined with another two separate techniques, AHP based and Parametric. Both AHP and Parametric models are under development. Mathematical equations were developed based on ENSURE's system activities that have been identified within the WBS. The cost model takes public cloud storage facilities and private OpenStack based storage options. It is expected that the total preservation cost is going to be represented by the cost of ingesting, the cost of archiving and the cost of accessing the data. The following formulae are the high-level formulae of the developed cost model.

- $$\text{Ingest Cost} = \text{Information Package generation cost} + \text{Quality check cost} + \text{metadata generation cost} + \text{Data protection for ingest cost}$$
- $$\text{Storage Cost} = \text{Data Transfer Cost} + \text{Storage cost}$$
- $$\text{Data Management Cost} = \text{Fixtity check cost} + \text{Reporting cost} + \text{File deletion cost} + \text{amendment to metadata cost} + \text{access audits cost}$$
- $$\text{Access Cost} = \text{Information Package retrieval cost} + \text{Data Protection for Access cost}$$
- $$\text{Transformation Cost} = \text{Data Migration cost} + \text{Virtual Appliance initiation cost}$$

5 INITIAL VALIDATION

A dual validation is designed for this research project, Qualitative and Quantitative. For the initial stage of the research most of the validation is done qualitatively through experts' opinion. Weekly consortium conference call meetings and regular online workshops are carried out, to validate both breakdown structures, WBS and CBS, the whole lifecycle of LTDP and sector differences. When finalising the framework, quantitative validation methods will be employed to validate the framework's output and behaviour. This will be done through at least three case studies.

6 CONCLUSIONS

Cost models for LTDP that have been developed over time has primarily focused to serve the library or the scientific centres communities; so all activity studies, case studies and breakdown structures are most suitable to these business sectors. This makes it clear that no work has been done for developing a cost model for LTDP for the financial sector, healthcare sector and clinical trials sector. These sectors are highly interested in digital preservation for two main reasons. Primarily that it is a legal obligation on all of them to keep their data for at least 5 years, some up to 30 years and even more. The other important reason is that these businesses do not want to lose valuable data they paid to generate since it will cost them higher to acquire again. None of the existing cost models attempted to calculate costs for cloud computing utilisation in digital preservation; while it is known that cloud computing should decrease the initial costs and the effect of obsolescence on cost. Another critical point in this discussion is risk, uncertainty and obsolescence in digital preservation. Previous cost models did not take into account the cost of mitigating obsolescence. This is a major drawback for previous long-term digital preservation cost models, because the idea of being long-term effective is mitigating obsolescence. Thus it is highly important to investigate what are the actual issues of obsolescence facing long-term digital preservation. Then investigate the possibility of including the cost impact of mitigation activities within the cost model being researched. Finally the research results provide a solid step towards the final development of the cost estimating framework for LTDP activities.

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REQUIREMENTS ANALYSIS FOR DECISION-SUPPORT SYSTEM DESIGN: EVIDENCE FROM THE AUTOMOTIVE INDUSTRY

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ABSTRACT

The purpose of this paper is to outline the requirements analysis that was carried out to support the development of a system that allows engineers to view real-time data integrated from multiple silos such as Product Lifecycle Management (PLM) and Warranty systems, in a single and visual environment. The outcome of this study provides a clear understanding of how engineers working in different phases of the product-lifecycle could utilise such information to improve the decision making process and as a result design better products. This study uses data collected via in-depth semi-structured interviews and workshops that includes people working in various roles within the automotive sector. In order to demonstrate the applicability this approach, SysML diagrams are also provided.

Keywords: requirement analysis, decision support system, automotive.

1 INTRODUCTION

Decision-making within automotive manufacturers has become more complex due to the number of participants involved, the volume and the structure of information required, and the high number of interrelated functions that are impacted both upstream and downstream in the value chain. Such organisations aim for “right first time” decisions by allowing engineers to make better decisions through the utilisation of information. Throughout the product lifecycle, from concept definition and design to the final assembly and the in-service support, Original Equipment Manufacturers (OEM) work closely with the suppliers to bring products to markets earlier and meet customers’ expectations while reducing costs. During the last decade the evolution of information technology has improved the collaboration and integration of companies. Enterprise applications such as ERP, PDM and PLM are evolving in order to support the decision-making process within the supply chain. However the large amount of information exchanged within the supply chain throughout the whole product lifecycle has created the landscape of “Isolated Islands of Information” where information is locked in different repositories making it difficult to share (Mahdjoub et al. 2010). Although some of these systems allow the information exchange in a dynamic and direct way, organisations still need to work closely with suppliers to improve the decision making process and the entire supply chain performance (Fiala, 2005; Rungtusanatham et al., 2003). Companies are also restricted by their internal legacy systems, usually developed to support proprietary methods of working. While information exists inside organisations, the integration of those disparate sources is currently missing.

Rupnik et al. (2006) defines decision support systems (DSS) as interactive computer-based systems intended to help decision makers utilise data and models in order to identify problems, solve problems and make decisions. DSS are designed to support decision makers by providing the right information at the right level in order to minimise the decision efforts while increasing the decision efficiency. In order to do so, engineers need to be able to reduce the amount of time spent searching for information and access the right information from the multiple silos required in order to make better decisions.

The purpose of this work is to outline the requirements analysis that was carried out to support the development of a system that allows engineers both internally and in the supply chain to visualise data integrated from multiple silos. The methodology presented demonstrates the approach that was followed to ensure that user requirements have been fully specified and transformed into system functionality in order to meet customers' expectations. It ensures that the requirements can relate the business objectives with the use cases while ensuring that the system developed is capable of meeting the user requirements. SysML diagrams were also developed to document, validate and communicate user requirements with the stakeholders while developing the system. In this paper, a SysML use case and a SysML requirement example is presented to show the methodology applied in relation with the business scope of the system.

2 RELATED RESEARCH

Davis et al. (2007) defines requirements engineering (RE) as the discipline of determining, analysing, pruning, documenting, and validating the desires, needs and requirements of stakeholders for a system. RE is a critical activity for the success of every software system. It allows engineers to capture user requirements and transform them into system functionality. Moreover RE can be used as the basis for planning, validating and testing the system (Konrad and Gall, 2008). There are several techniques for capturing and analysing requirements. Jiang et al. (2008) evaluated the most common techniques used in each phase of the RE process and proposed a methodology called Methodology for Requirements Engineering Techniques Selection (MRETS) to support the selection process by enabling engineers to link the attributes of the project with the attributes of each RE technique. Konrad and Gall (2008) discussed the challenges associated with requirements engineering in large-scale projects. The lessons learnt presented in Konrad and Gall (2008) were instructive in supporting the development of the proposed methodology.

One of the key parts of any RE technique is the modelling technique used for the analysis, documentation and validation of the requirements captured. During the last decade UML and SysML diagrams have received significant attention as they provide a common language in order to better understand the developed systems. Chauldron et al. (2012) provided empirical evidence to demonstrate the effectiveness of UML modelling. Soares et al. (2011) proposed a structured approach for capturing and communicating requirements specifications using standardised models such as SysML requirements diagrams, SysML tables and SysML use case diagrams. UML and SysML are widely used and contribute in transforming user requirements into system behaviour while at the same time offering a shared understanding and enabling more effective communication through a standardised language. However, Schulz (2001) stated that most UML-based methodologies are focus on the solution and define the system functions using use-case diagrams instead of addressing the business-oriented application requirements, proposing a requirements-based UML methodology to support the development method.

3 METHODOLOGY

Figure 1 shows the holistic approach that was followed to gather, analyse, manage and document requirements. Due to space limitations only the highlighted area of this methodology will be presented in this paper.

Requirements elicitation was conducted through semi-structured interviews and workshops with various members of the automotive industry such as OEMs and other actors in the supply chain. All the interviews arranged were face-to-face and included people from various roles such as Quality Managers, Quality Data Managers, Warranty Engineers etc. In several cases, interviews were conducted with a group of people in order to include technical people and engineers who are the actual users of the systems involved. Through the requirements elicitation approach a generic

requirements catalogue was created to ensure that the solution could be applied in different areas of the business. A low-level requirements catalogue was also created to capture requirements for specific use cases and form the basis for the development of a proof-of-concept system. The low-level requirements captured highlight the business requirements defined from the users without taking in consideration what the solution will look like. As Schulz, 2001 defines this catalogue answers the what? question rather than the how?. The requirements catalogues were then prioritised according to the MoSCoW ratings (Tudor and Walter, 2006 ; Hatton, 2007). Hatton, 2007 demonstrates different prioritisation methods and states that significant benefits can be achieved through early prioritisation. The MoSCoW method is probably the best choice as it is simple to perform and defines very accurate priorities.

- (M)ust have: Requirements that represent the core elements of the proof-of-concept system. Failure to meet these requirements will have an impact on the success of the project.
- (S)hould have: Represents high-priority requirements that would be an advantage to have in the early prototypes. Selection of these requirements depends on the project resources.
- (C)ould have: Features that are usually considered as “under development”. These requirements are desirable to have but they can be omitted if necessary.
- (W)on’t/(W)ant to have: These requirements are not unimportant but they are recognised as requirements that will not be part of the proof-of-concept system. These requirements are an important element in an incremental approach as they can be used during the next phases of the development.

A preliminary business-case analysis was conducted to support the development of a system. SysML diagrams such as requirements diagram, use case diagram, activity diagram and sequence diagrams were created based on the low-level requirements catalogue to transform the user requirements into system functionality. The SysML diagrams created were also used as a communication method between stakeholders and system developers to share a common understanding of the system; in addition SysML models were used as a validation point throughout the development of the system. A traceability matrix was created to ensure that test cases can be linked back to the use cases to ensure that the outcome of the system developed will always meet customers’ expectations. This tool helped in tracing the source requirements to their low/test level and from their low/test level back to source (Soonsongtane and Limpiyakorn, 2010). Cost-benefit analysis will be carried out at the end of this project to measure the outcome and justify further investments required. Throughout the whole process, requirement management activities were carried out to manage and validate the outcome of this methodology.

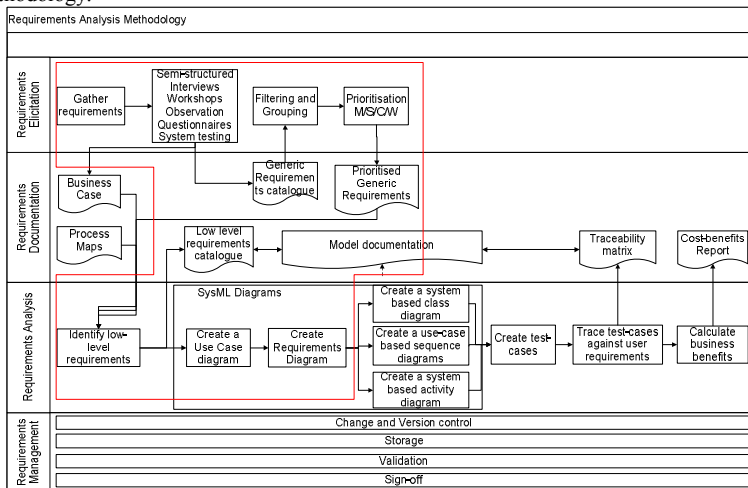


Figure 1: Requirements Analysis Methodology

The proposed methodology ensures that the system developed will satisfy the business requirements and as a result bring benefits to the business and its supply chain. The use case presented in the next section demonstrates one part of the system developed and shows the applicability of the above methodology followed.

4 RESULTS

One of the objectives of this integrated solution is to support the Quality department of the case study company to improve the time to detect and resolve an issue. As such this department is responsible for reducing the need for repairs and therefore cost of warranty claims, responding to customer feedback, and ensuring that the dealers are equipped sufficiently to repair the vehicles in the appropriate manner. In order to meet these objectives, this department has a close working relationship with suppliers by providing all the information required whilst monitoring their performance throughout the analysis of faults during manufacturing and in-service. There is a common requirement to reduce the time engineers, within the OEMs and the supply chain, spend on searching for information as opposed to resolving customer concerns. The application targets of this system are to support the decision-making process by allowing engineers to investigate data, more deeply and to further enrich the level of knowledge within less time. Moreover by gathering relevant data, engineers will be able to understand the customer issues and the dealer diagnosis and repair methods used in relation with other important supporting information. This process will allow them to improve the dealer diagnostic, repair, or warranty returns analysis procedures, close the information gaps and reduce the amount spent in warranty returns.

4.1 Establish Use Case Model

SysML use case diagrams provide a good graphical representation of the functional requirements of a system as they illustrate the different use cases, the actors and their interactions with the system. Actors may include users, systems or any other entity that has a direct or indirect communication with the system (OMG, 2002). A SysML use case diagram is shown in Figure 2. Within the boundaries of the diagram each use case is associated with a unique ID and as a result low level requirements and test cases documented later in the process can be traced back to the source use case. Outside the boundaries the diagram demonstrates two types of actors. Firstly it shows the actual users of the system such as: 1) Quality managers who are responsible for monitoring the performance of a supplier. The system will enable these actors to overview the quality process by accessing all relevant information in a less time-consuming way. 2) Warranty reduction engineers who are responsible for delivering the quality projects raised by analysing different types of data such as faults recoded by customers. They are responsible for assigning liabilities on the faults found and ensuring that the dealers are equipped sufficiently to repair the vehicles in the appropriate manner. 3) Supply Chain engineers have similar tasks within their own organisations and they require the capability to integrate data coming from dealers as well as other types of data provided by the OEMs in relation with their own internal systems. Secondly SysML use case diagrams show the different types of system that need to be accessed: 1) PLM systems that hold the product data such as CAD data and 2) Data Silos, usually developed within organisations to hold all the other meta-data required to support the decision process.

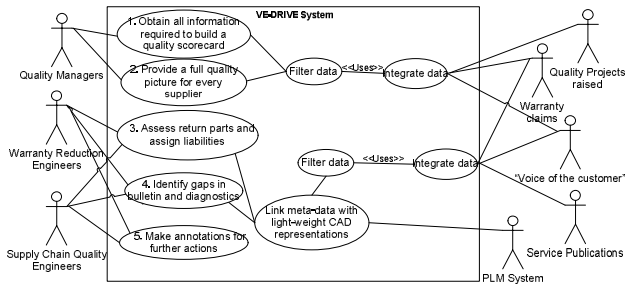


Figure 2: SysML Use Case Diagram

4.2 Establish the Requirements Model

The SysML requirements diagram is a standardised way of decomposing high-level functional requirements from the use case diagram into low level requirements while showing the relationships between them. It also represents the relationships drawn from text-based requirements with additional modelling elements (OMG, 2002). The basic template for a SysML requirement diagram includes the ID, the name and the text. The diagram shown in Figure 3 uses the approach proposed by Soares et al. (2011) and includes the MoSCoW ratings prioritisation for each one of the low-level requirements. Developing a system that is capable of fulfilling all the user requirements captured is not always feasible. Prioritisation will support the selection of the “Must” and “Should” requirements that will be used in developing a proof of concept system. Having the prioritisation within the SysML requirement diagram will allow the analyst to calculate the risk of a requirement that has not been met as well as determine its impact on the whole system based on the relationships defined. The diagram shown expands on two of the use cases presented in the previous use case diagram. For simplification reasons only a sample of priorities are included in the diagram below.

During the requirements elicitation process it was highlighted that engineers spend a significant amount of time searching for information and manually accessing disparate silos. As warranty engineers work in a later phase of the product lifecycle accessing information held in PDM and PLM systems could be a challenge. In order to improve the decision making process it was highlighted that it is critical to support the engineers on gathering relevant information in a single visual environment. The requirements analysis showed that it is critical for engineers to view different clusters of data in a single environment in order to build a full quality picture for a part, sub-system or whole system. Data such as the “voice of the customer” (surveys, feedback from forums, breakdown and recovery reports); service and repair publications (manuals, bulletins and diagnostics); product data (CAD data, specifications and tolerances) and warranty claims and faults recorded from the dealers are critical in order to build a full quality picture. Although every use case in Figure 2 is linked with the SysML requirements diagram for the sake of simplification only elements of use case number three and four will be decomposed in Figure 3.

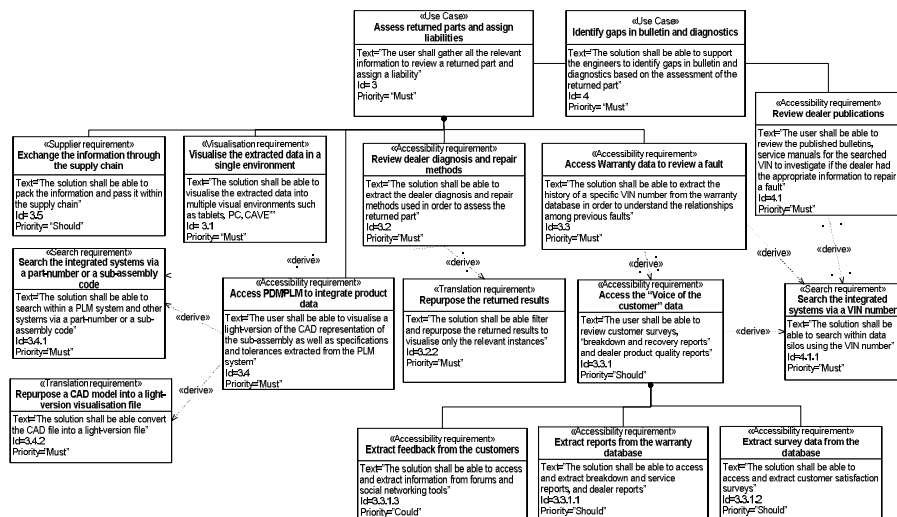


Figure 3: SysML Requirements Diagram for the Quality Use Case

5 CONCLUSIONS

The requirements gathered and described through SysML modelling diagrams will drive the development of a novel system that allows engineers to integrate and visualise, in a single environment product data from PLM systems in relation with other meta-data such as warranty data leading to an improvement in the decision making process. Due to space limitations, the transformation of business scope requirements into system functionality through SysML diagrams has not been presented in this paper. The methodology presented shows the holistic approach that needs to be followed in order to develop a proof-of-concept system that validates the requirements captured. Though this paper concentrates on the quality department use case requirements the wider purpose of the system is to support multiple engineers working in different phases of the product lifecycle.

ACKNOWLEDGMENTS

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BENEFIT REALISATION MODELLING FOR ERP SYSTEMS USING SYSTEM DYNAMICS

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ABSTRACT

Achieving success for ERP systems is not only concerned with deploying the technology on time and on budget but also concerned with the level of achieving targeted benefits from the system. This level of achieving targeted benefits can be managed indirectly through managing the organisational attitude toward the new system. Thus, the aim of this paper is to use the System Dynamics (SD) to reveal how managing organisational attitude leads to an increase in the level of system use and, therefore, leads to a decrease in the level of resistance to change to new system for achieving high level of performance. SD is used to investigate the causal loops of organisational attitude, perceptions, behaviours, and policies taken to achieve desired benefits. The ability to manage an organisational attitude toward ERP is an important factor for achieving desired levels of benefits is the main conclusion of this research.

Keywords: ERP, System Dynamics, Benefit Realisation.

1 INTRODUCTION

Enterprise Resource Planning (ERP) is an enterprise wide system that integrates information across various departments. Like the new management system, ERP system could face resistance by the stakeholders such as employees, customers, and vendors. This resistance could be because of the fear of changes that could affect their job nature, fear of the inability to use the system easily, and fear that this new change will not add value to their work or even harm the work. These attitudes, and also their consequence behaviour of resistance, come from the perception of, or attitude toward, this new technology. As a result, the ability to manage these attitudes through managing perceptions could improve the adaptability process of new ERP system.

About seventy per cent of new Information Systems (IS) projects could not achieve the targeted performance (Clegg et al., 1997). One of the reasons that explain this phenomenon is the care after implementing these systems. Most of ERP vendors, and the adopting organisation, consider their ERP implementation projects finished just after delivering the system and training employees. In fact, after ERP implementation, the performance of organisation declines shortly because of the adaptation process (Shang and Seddon, 2000). The performance needs on average from 2 to 3 years in order to increase the performance significantly (Nicolaou, 2004). Nevertheless, this is not the case for all ERP adopting organisations; many of them fail and go to bankruptcy after implementing ERP (Davenport, 1998). This is an indication that organisations that adopt ERP should manage the post-implementation period effectively in order to manage this risk as well as being able to manage the decline in the performance in a good manner. There are factors important for the effectiveness of benefit

management (Breese, 2012) such as organisational culture, timing and capacity for change, and governance and ownership. Organisational culture, timing and capacity for change, and governance and ownership are three factors that are covered in this research. Ownership problem which focuses on who is the responsible for achieving, tracking, and measuring benefits? Therefore, it is addressed that benefit Realisation process should be done in project (Breese, 2012; Pellegrinelli et al., 2011; Bradley, 2010) called in this research Benefit Realisation Project (BRP) team.

Since ERP benefit Realisation project, as any organisational change, could have an impact on the organisation performance, the results should be simulated first before the project starts. Not only simulation matters, but also the indicators used and the required actions by BRP team should be addressed.

A system dynamics model looks like a control system that has thermostat in order to manage a certain process (Coyle, 1996). The model consists of indicators, actions, and intermediates. Intermediates are mainly the perceptions of the user. BRP team has controllable variables, actions, which can be used to manage the level of achieving benefits. These actions are assumed to have impacts on the perceptions of the user. Perceptions affect the attitude, positively or negatively, which lead to change in users' behaviour (Ajzen and Fishbein, 1977) (i.e., resistance to change or use). Behaviours and attitudes could be measured through indicators. Gap between targeted indicator level and the actual indicator level motivates BRP team to take corrective, balancing, actions in order to re-align the actual adaptation process to the planned one. As a result, if system dynamics could indicate, through simulation, the targeted indicator level for attitude and behaviour to achieve a certain level in benefits, and if the BRP management should act in a way to balance the negative loops of consequences, system dynamics should be used to model BRP team actions to achieve the targeted level of benefits. Therefore, the aim of this research is to investigate how actions taken by BRP team affects the targeted level of benefits through managing organisational attitudes and perceptions toward the new ERP system using System Dynamics.

2 LITERATURE REVIEW

Benefits Management is "the process of organizing and managing such that the potential benefits arising from the use of IS/IT are actually realized" (Ward and Daniel, 2006). Based on this definition, the aim of benefit Realisation management is to achieve the targeted performance. Targeted performance is always planned according to the capacity and the ability of the information system only without taking into consideration the capacity and the ability of the people to change (Jenner, 2009).

People always resist to new changes. That is why they take time to adapt themselves to the new system. Adapting to new system is mainly based on the level of acceptance to the new system. Therefore, it is worth to mention earlier works in system acceptance and system success theories. On one hand, system acceptance theories focus on why, and how, do user, or organisation, accept or reject new system. On the other hand, system success theories focus on explaining the interdependence between different dimensions of success factors such as perceived ease of use, perceived usefulness, use, intention to use, and perceived net benefit. According to Delone & McLean (2003), net benefits could be operationalized based on the context and the type of information system. Finally, representation theory (Burton-Jones and Grange, 2012) focuses on the adaptation process to achieve the effectiveness in the use.

On one side, current benefit Realisation models do not consider the adaptation rate factor. Adaptation rate is the speed of realizing benefits from the ERP system. Although system acceptance and success considers the social and psychological factors, these theories do not consider the actions required to achieve the targeted performance. Even though Burton-Jones & Grange (2012) considers actions required to increase the adaptation rate, they focus only on learning variable. Therefore, Type and duration of learning, the way of managing the relationship with the vendor, and motivational ways for using the system are three factors that considered in this research to fulfil the research gap. Moreover, the research develops new benefit Realisation model that considers the human capacity required, i.e. psychological factors such as attitude; perception; and behaviour, for achieving targeted benefits. This research uses the relations in Table 1 to develop new benefit Realisation model based on organisational social capacity to adapt to the new ERP system.

Table 1: System Success and System Acceptance Theories

Theory	Reference	Relations
System Acceptance Theories	Theory of Reasoned Action (Fishbein and Ajzen, 1975)	Subjective Norms (How others perceive the intended behaviour) & One's Attitude → Behavioural intention → Behaviour
	Technology Acceptance Model (TAM) 1 (Davis, 1993)	System Design Features → Perceived usefulness & Perceived ease of use Perceptions → Attitude Attitude → Actual System Use.
	Technology Acceptance Model 2 (Venkatesh and Davis, 2000)	Factors that affect Perceived Usefulness: 1) Subjective norms 2) Image 3) Job Relevance 4) Output Quality 5) Result Demonstrability. Perceived Ease of Use → Perceived Usefulness Perceived Ease of Use & Usefulness → Intention to use → Usage behaviour.
	Unified Theory of Acceptance and Use of Technology (UTAU)	Factors that affect Behavioural intentions: 1) Performance Expectancy. 2) Effort Expectancy. 3) Social Influence. Factors affect Actual Use: 1) Behavioural Intentions. 2) Facilitating Conditions.
System Success Theories	(DeLone and McLean, 1992)	System Quality → Use, User Satisfaction Information Quality → Use, User Satisfaction Use ↔ User Satisfaction Use, User Satisfaction → Individual Impact Individual Impact → Organisational Impact
	Delone & McLean (2003)	System Quality, Information Quality, and Service Quality → Intention to use System Quality, Service Quality → User Satisfaction → Intention to Use Intention to Use → Use → User Satisfaction → Intention to Use Use, User Satisfaction → Net Benefits Net Benefits → Intention to Use, User Satisfaction.
Representational Theory – Effective use	(Burton-Jones and Grange, 2012)	Action → Consequence → Perception → Difference between what is planned and targeted → Action Adaptation Actions: Surface (Interface), Physical (Hardware), Deep structure (new business process) learning → Effective Use

3 SYSTEM DYNAMICS MODEL

System Dynamics model is different from any other causal model since it takes into consideration a couple of important factors: namely, loops, either positive enforcing loops or negative balancing loops, and time lag, in terms of rates (Stermann, 2000). Since benefit management should be based on a loop of steps: identifying; planning; executing; and reviewing, this research is based on the same philosophy but with taken into consideration system acceptance and system success theories. Moreover, people could change at an adaptation rate to this new system and, therefore, to achieve the

targeted benefits. Rate means that something over time factor. Therefore, system dynamics modelling is suitable for simulating and managing benefits targeted from ERP system.

Actually, behaviour is always driven by attitude. Additionally, attitude is based on what is perceived from experience, from background, or from learning process. Accordingly, affecting what is perceived could affect the attitude toward this object and this in turn leads to change in behaviour (Fishbein and Ajzen, 1975; Ajzen and Fishbein, 1977). What is perceived is affected by many factors such as information systems readiness, duration and content of learning process, the experience with using the system, and the relationship with the ERP vendor. These factors could be managed and controlled by BRP team in order to manage the behaviour of users toward the intended goal. Affecting attitude may be insufficient to manage the performance, or the effective use of the system, alone. Thus, deliberate motivational activities by BRP team should be used to increase the use. BRP team could use extrinsic motivations such as money and promotion or intrinsic motivations such as psychological rewards (e.g. recognition rewards, or certificates). Behaviour could take three forms: resistance to change, use, or effective use. Managing what is perceived should be directed to affect the behaviour to achieve the effective use behaviour.

The managing process of behaviour should take the closed-loop shape. As illustrated in Figure 1, this process should not only be based on actions, policies, that affect the adaptation level but also it should consider information regarding the current state in order to manage this process effectively.

To sum up, action, or policy, of BRP team should affect the perception of the organisation which affects the attitude level toward ERP. This attitude will be translated into behaviour. Positive attitude will lead to more use and effective use. On the other hand, negative attitude will lead to less use and more resistance to change. The general model could be illustrated in Figure 1.

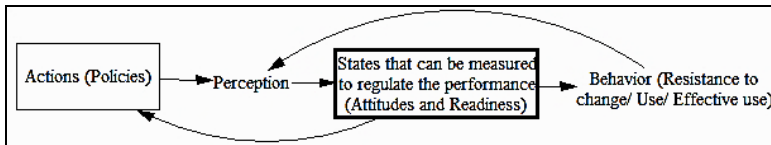


Figure 1: Benefit Realisation Management Model

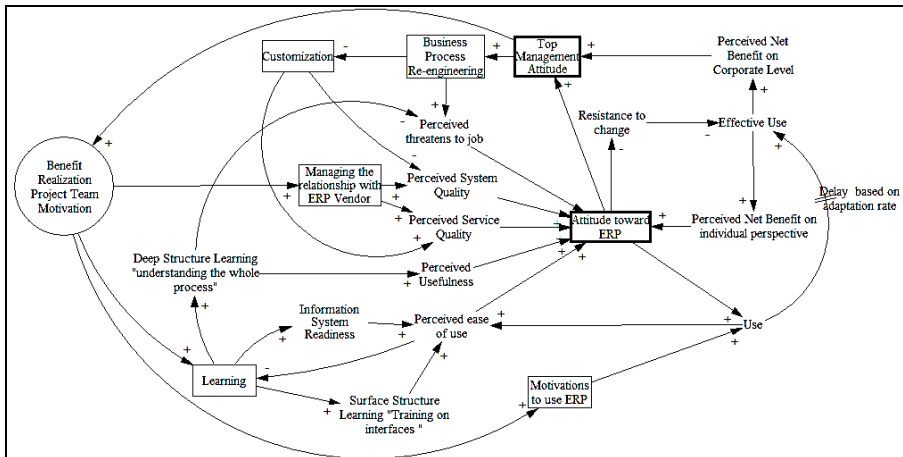


Figure 2: Benefit Realisation Management using System Dynamics Model

The loop comes because this behaviour affect again on the perception. For example, more use will lead to more perceived ease of use. More perceived ease of use will affect positively on the organisational attitude toward the ERP system. Also the state level, attitude level, could be used as an

indicator for BRP team to increase or decrease the level of actions such as learning duration, more close managing relationship with ERP vendors that could affect in turn the organisational perception toward ERP. According to Figure 2, Benefit Realisation Project Management Motivation circle is the level that affects all decisions and actions taken by BRP team. Black Boxes are the decisions, actions, or policies that taken by BRP in order to regulate and manage the state, the organisational attitude level. Black Bold Boxes are the attitude levels that should affect the behaviour. Other shapes are the behaviours and perceptions of the organisation toward different policies.

BRP Team has three controllable actions that could be used in order to increase the adaptation rate and; therefore, achieve the benefits effectively. Learning, managing the relationship with ERP vendor and motivations to use the system are three controllable policies. The fourth policy, the last resort for BRP team, is either business process re-engineering or customization of the system since all efforts are failed to fit the organisation to ERP system. This decision is not easily taken since it requires top management acceptance.

Employees' learning process (Burton-Jones and Grange, 2012), either on ERP interface or on the understanding the new business processes, affects the perception of employees significantly. More hours training on interface, the more the perceived ease of the system will be. Additionally, not only perception of usefulness by employees will be from learning about the new business processes resulted from the use of ERP system, but also perceived threatens to their current jobs should be reduced because of the understanding how much they become useful and added value than before.

Managing relationship with vendor is very important for the perceived system quality and service quality. The more employees feel that their ERP related problems solved fast, the more the perception of service quality will be. In other words, the more the responsiveness, engaging, and commitment of ERP vendor, the more the service quality will be perceived by the organisation. Likewise, the more the actions lead to perceptions that system has less bugs or errors; the more the system quality is perceived by the organisation.

These perceptions are pooled cross time into the attitude pool. Attitude could be positive or negative toward the ERP System. Based on this attitude, users will use the system or users will resist to the new system. Although attitude is very an important factor in explaining the use behaviour, attitude may not be sufficient for motivating users to use the system. The policy of motivation should come into effect to motivate to use either in an intrinsic way such as certification for the best user or in an extrinsic way by linking the use behaviour with bonus and salaries.

Indeed, the use behaviour, in itself, affects the ease of use perception, since more use of the system; the more familiarity with it will be. The loop will until the use behaviour achieves a higher level which is the effective use. Effective use means using most of reports and features of the system which lead in turn to achieving the targeted benefits. Also an enforcing loop that affect the effective use behaviour which is positive attitude leads to reduction in resistance to change. This reduction in resistance will increase the effectiveness of the use. More effectiveness in the use will lead to perceived net benefits. This perception will lead to a positive attitude. This at the end will lead to a nested of virtuous loops.

The effectiveness in use by the organisation will lead to achievements of targeted organisational benefit from ERP. These achievements and the positive organisational attitude will be reflected on top management attitude toward the ERP system and the performance of BRP team. Certainly, the positive attitude will be reflected into more authority and more power to the BRP team. BRP team will be more involved and motivated to achieve more objectives.

4 CONCLUSION

Benefit Realisation process is a dynamics process; one action, or ignorance to take the action, may exacerbate the situation that leads to exponential speed toward success or failure in achieving the targeted benefits. The ability to manage organisational attitude and perception toward ERP system is a key factor for determining the rate of achieving targeted benefits. Perception of achieving targeted benefits becomes a feedback for closing the loop of BRP team motivation and managing the organisational attitude and perceptions through top management commitment toward the ERP system.

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Forming, Casting and Machining

OPTIMIZATION OF ROUGHING OPERATIONS IN CNC MACHINING FOR RAPID MANUFACTURING PROCESSES

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ABSTRACT

This paper presents a method for optimizing roughing operations in CNC machining particularly for parts production through a subtractive rapid manufacturing process. The roughing operation in machining is primarily used to remove the bulk of the material and to approximately shape the workpiece towards the finish form. The manufacturing process described utilizes a 3-axis CNC machine with an indexable 4th axis device that is used to hold and rotate the workpiece. The method used is derived from the multiple approaches in roughing operations that differ in the number and the angle of the orientations. Most of the machining parameters are generalized throughout the process to allow some automation in generating the machining program. Overall, the performance of each of the approaches is evaluated based on the lowest machining time to produce the part.

Keywords: Roughing operation, CNC machining, Rapid manufacturing.

1 INTRODUCTION

In recent years, the ability of rapid manufacturing(RM) in producing identical parts has been widely recognised; this technology being used in many areas of production such as moulds and tooling, biomedical parts and customized products. Various tools and methods have been developed to cater for parts production in RM. Additive manufacturing (AM) is a method that creates parts on a layer basis by adding and stacking the material. However, this technology is still constrained by issues such as material properties, part accuracy, cost and performance (Campbell, Bourell and Gibson 2012). On the other hand, adopting Computer Numerical Control (CNC) machining as RM process seems to be a feasible approach to surmount the weaknesses of AM. CNC machines possess the highest degree of accuracy and repeatability and at the same time is capable of processing wide variety of materials. The process minimizes the staircase effect that usually found in AM and operates at minimum cost (Yang, Chen and Sze 2002). This distinct feature leads to the possibility of further enhancement of the CNC machining process to fulfil the rapid requirements of the RM process. There are some approaches that have been developed to deal with the pre-process engineering and setup planning issues in CNC machining.

One approach is the use of a 3-axis CNC milling machine with an indexable 4th axis device to hold and clamp the workpiece on the machine table. This approach allows the slicing process to take place at various rotations of one axis and is able to produce complex shapes and features (Frank, Joshi and Wysk 2002). The indexable device is used to clamp the workpiece and allows it to rotate about one axis. This method employs layer-based material removal from multiple orientations until all surfaces of the part are machine without refixturing (Frank, Joshi and Wysk 2003). Dealing with a variety of machining orientations requires proper process planning to achieve reliable process efficiency. During the machining process, the surfaces contained in the part geometry must be visible in some direction. Figure 1(a) illustrates the visibility of part surface from one orientation (arrow

direction). The other surfaces that not visible on this orientation require another orientations as shown on figure 1(b) and 1(c). Based on this method, visibility program is created to determine the minimum set of orientations required to completely machine the part (Frank, Wysk and Joshi 2004). Depending on part geometry and complexity, this program is able to propose orientation angles that will guide the tools to remove material until the final shape becomes visible.

Within each orientation proposed by visibility program, roughing and finishing operations are performed one after the other, the operations being different in terms of tool usage and machining parameters. The roughing operation aims to remove large amounts of material whereas the finishing is concerned with getting the exact shape of the part. As illustrated in figure 1, during the first roughing operation, the material removal process occurs until the furthest possible surface is reached or the workpiece is fully cut (Frank 2007). Consequently, the roughing tool selected must be of adequate length to cut through the workpiece. During roughing operations, it is important to avoid the formation of a thin layer material that could possibly wrap around the tool and cause failure. Thus, cutting through the workpiece or machining from at least three orientations are viable techniques to prevent thin layer formation. Next, the process continues with the finishing operation that will machine until the centre radius of the round workpiece. After that, the workpiece is rotated to second orientation. Then, the roughing and finishing operation is repeated again. At the end of the process, small diameter cylinders are left to connect the finished part and the workpiece. These cylinders act as sacrificial supports that will be removed later on as part of post processing.

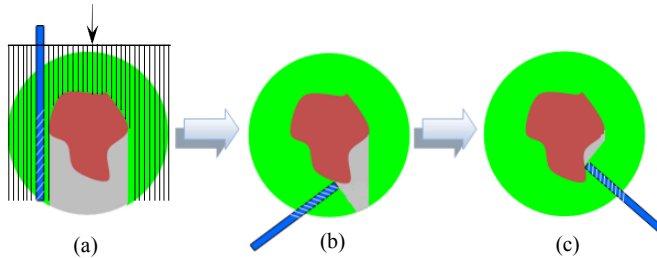


Figure 1: Roughing operation approach in CNC machining (Frank 2007)

The orientations proposed by visibility program are mainly effective during the last stage of machining (the finishing operation). In order to minimize the number of orientations required to machine the part, the visibility program incorporates the roughing operation together with the finishing operation under one same orientation. In future, further development it is proposed to use the initial angle to assist the visibility program in sequencing and optimize the orientations (Renner 2008). The initial angle is determined based on the angle at which most of the surfaces of the part are visible to machining. Starting the initial angle as first orientation, the rest of the orientations are generated to cater less uncovered surfaces. Hence, providing this angle to the visibility program minimizes the orientations set and is most likely to reduce total machining time for the process.

Referring to the current approach in adapting CNC machine for the RM application, there are two issues that should be emphasised. First, rotating the workpiece on the indexing device guarantees process continuity without any refixturing task. However, the orientations proposed constrain the roughing operation which must be performed within the finishing operation. To the contrary, instead of relying on surface visibility to decide the orientation, it is possible to execute roughing operations with a different set of orientations that aims to achieve high volume removal. In machining, time is one of the major concerns that will influence the process efficiency. The roughing operation can be considered as one of the time consuming processes especially in mould and die manufacturing that involves massive material removal (Hatna, Grieve and Broomhead 1998). Thus, it is important to maintain proper control and sustain the process efficiency in roughing operations. The second issue relates to the cutting tool penetration at the beginning of the process. Roughing tools need to cut the material till the furthest possible depth with the intention of avoiding thin material formation. This might increase the risk of tool failure because the tool can easily deflect due to the cutting forces

generated. Increasing the contact length will influence the tool performance as it tends to effect the tool temperature and causes flank wear (Sadik and Lindström 1995). Based on these issues, this paper presents a methodology and approach to optimising the roughing operation in CNC machining for the RM application.

2 OVERVIEW OF METHODOOGY

Machining orientations for roughing operation are developed to accommodate the orientations proposed by the visibility program. Two approaches are used. The first approach proposes additional orientations for the roughing operation instead of just relying on the orientations provided by the visibility program. The second approach is based on extracting and splitting the roughing operations contained in the visibility program and assigning them to other independent orientations that are not bound with the visibility orientations. Machining simulation has been conducted to evaluate the practicality of both approaches and to discover the optimum roughing orientation angles. As the process employs a feature free approach, most of the machining parameters remain constant throughout the process except for the roughing orientation angles. Simulations are run through NX7.5 software via customized coding that simulate the machining program based on the angle input. This coding generates detailed machining times for the roughing operation, finishing operation and non-cutting movement. Consequently, it also assists the simulation in running automatically given the required inputs. Overall performance was evaluated by comparing the total machining time generated from the series of simulations. Figure 2 summarizes the methodology employed to optimize the roughing operation in CNC machining.

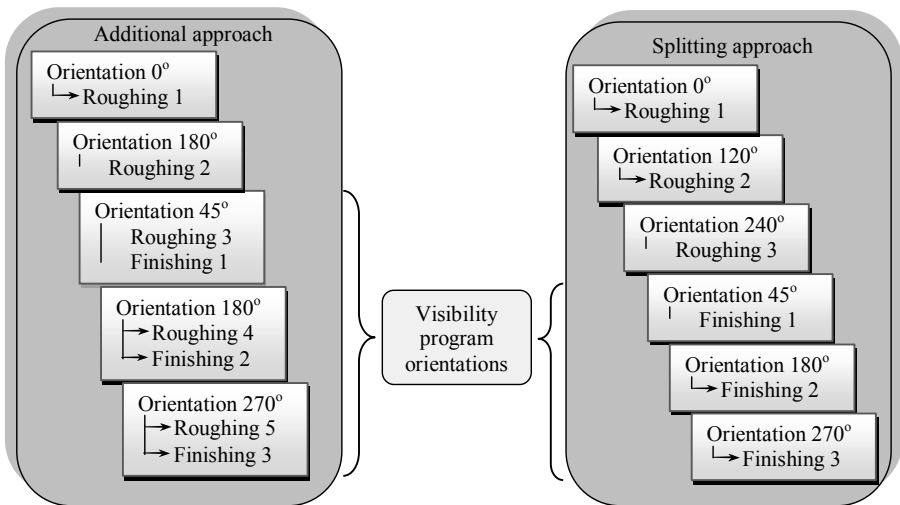


Figure 2: Two distinct approaches to find optimum roughing orientations.

2.1 Additional Roughing Orientation Approach

This approach involves introducing an extra machining orientation to the current orientation set. Two methods are proposed in this approach. The first one is adding one roughing orientation that cuts material until the centre of the round workpiece is reached. Simulation for this method starts at angles from 0° to 359° . The second method deals with two additional orientations. These orientations are represented at 0° and 180° . The angle is increased gradually in each simulation through increases of 1° from 0° to 179° and from 180° in increments of 1° to 359° . To avoid the formation of thin material, the cutting only proceeds until the circumference of the sacrificial support cylinder is reached. The thick

material left will be removed later by other roughing operations. The idea of having these additional roughing orientations is mainly because it is possible to remove more material and shorten the roughing process in visibility orientations.

2.2 Splitting Roughing Orientation Approach

Instead of adding to the number of orientations, this approach modifies the visibility program output by taking out the roughing operations and incorporating them with the other orientations. A few combinations of angles are identified to work on the roughing process. The combinations are built up from three and four angles that together generate five sets of roughing orientations. The set includes $(0^\circ, 120^\circ, 240^\circ)$, $(0^\circ, 135^\circ, 225^\circ)$, $(0^\circ, 120^\circ, 225^\circ)$, $(0^\circ, 135^\circ, 240^\circ)$ and $(0^\circ, 90^\circ, 190^\circ, 270^\circ)$.

Basically, the combination of three angles is a minimum requirement to roughly machine the part without forming any thin material that is hard to remove. Therefore, $(0^\circ, 120^\circ, 240^\circ)$ is the first combination set that equally divides the workpiece from one axis of rotation. The second roughing set $(0^\circ, 135^\circ, 225^\circ)$ has been developed based on the coverage area of the cylindrical shape workpiece. 0° degree covered the first half of the workpiece whereas the other two angles, 135° and 225° are used to cater for the other half of the workpiece (a quarter for each angle). The next two combination sets are derived from the first and second orientation sets. Two of the angle values from each orientation set are swapped to form $(0^\circ, 120^\circ, 225^\circ)$ and $(0^\circ, 135^\circ, 240^\circ)$ roughing combinations. Lastly, the four angle combination is used in roughing orientation to ensure extra coverage of the area and to reach all features presented on the part. The range between each angle is 90° but on the third angle the value is increased to 190° instead of 180° . The reason for this incremental value is due to the possibility of thin material formation during third orientation of roughing operation. Based on this orientation, the tool is guided to start the machining from an inclined position and shapes the part effectively.

3 IMPLEMENTATION

Using the method described above, experimental results were obtained by conducting a series of simulation studies using four part models; drive shaft (flange yoke), knob, salt bottle and toy jack. The models were selected randomly and consisted of a variety of different part features to form the object. Multiple features presented on part was important to test the effectiveness of the orientation sets that had been developed. Table 1 shows one of the results produced for the knob model. Based on this result, each of the orientation sets were compared by evaluating the machining time and efficiency.

In this work, an objective was to establish a methodology to identify a roughing orientation set that suits the rapid manufacturing process using CNC machining. Referring to the set of orientations proposed, the performance was analysed based on distinctive criteria as indicated in Table 2. The criteria were (i) minimum total machining time (ii) maximum roughing time (iii) minimum finishing time (iv) minimum non-cutting time and (v) maximum roughing percentage. Most of the criteria are filled up with four and two orientation sets. However, minimum non-cutting time suggested two other orientation sets which consist of three orientations and orientations proposed by the visibility program. The results from the different orientation sets vary between each model because of the different features presented on the parts. Nevertheless, roughing through four orientations set is the most favourable method for almost all models.

The Additional roughing orientations approach which included the adding one or two orientations managed to increase the material removal volume. However, this approach tends to increase the number of machining operations in comparison with the operations produced by the visibility program. Additionally, the angle used can be redundant to the roughing angle from visibility program and cause inefficiencies due to repetitive work. To some extent, thin material will form if the two additional angles share the same value with angles from the visibility program.

Table 1: Example result recorded during simulation study.

Result \ Roughing orientation sets	Visibility program	1 orientation	2 orientations (0°/180°)	3 orientations (0°/120°/240°)	3 orientations (0°/135°/225°)	3 orientations (0°/120°/225°)	3 orientations (0°/135°/240°)	4 orientations (0°/90°/190°/270°)
Machining time (hour:min:sec)	04:25:00	04:08:49	04:00:43	04:26:13	04:22:32	04:21:10	04:28:35	04:04:17
Finishing time (hour:min:sec)	03:03:47	02:49:53	02:39:28	03:00:51	03:03:49	03:03:39	03:04:50	02:38:50
Non-cutting time (hour:min:sec)	00:12:14	00:12:10	00:12:21	00:11:52	00:11:55	00:11:12	00:11:58	00:10:23
Roughing time (hour:min:sec)	01:09:00	01:06:46	01:08:55	01:13:30	01:06:47	01:06:18	01:11:47	01:15:04
Percentage of roughing time	26.0	26.8	28.6	27.6	25.4	25.4	26.7	30.7
Number of operations	7	7	8	6	6	6	6	7
Number of tool changing	5	5	5	1	1	1	1	1
Orientation set	180° 45° 315°	40° 180° 45° 315°	0° 180° 180° 45° 315°	0° 120° 240° 180° 45° 315°	181° 316° 46° 180° 45° 315°	181° 301° 46° 180° 45° 315°	0° 135° 240° 180° 45° 315°	90° 180° 280° 0° 180° 45° 315°

Table 2: Overall performance of orientation sets

Criteria \ Model	Drive shaft	Knob	Salt bottle	Toy jack
Minimum machining time	4 orientations 0°/90°/190°/270°	2 orientations 0°/180°	4 orientations 0°/90°/190°/270°	2 orientations 35°/215°
Maximum roughing time	2 orientations 91°/271°	4 orientations 90°/180°/280°/0°	4 orientations 0°/90°/190°/270°	2 orientations 35°/215°
Minimum finishing time	4 orientations 0°/90°/190°/270°	4 orientations 90°/180°/280°/0°	4 orientations 0°/90°/190°/270°	2 orientations 35°/215°
Minimum non-cutting time	4 orientations 0°/90°/190°/270°	4 orientations 90°/180°/280°/0°	3 orientations 45°/180°/275°	Visibility program 49°/140°/228°/320°
Maximum roughing percentage	4 orientations 0°/90°/190°/270°	4 orientations 90°/180°/280°/0°	4 orientations 0°/90°/190°/270°	2 orientations 35°/215°

Meanwhile, the split roughing orientation approach seems to be a feasible method to optimize the roughing operations. It allows the roughing task to be carried out independently without any reference to the other operations. At the same time, this approach reduced the number of tool change that only occurred once throughout the machining. It is good practice to minimize the number of tool change even if the CNC machine is equipped with an automatic tool change system (Lim, *et al.* 2001). Machining simulation through three roughing orientations demonstrates consistency in performance but does not generate a significant result. A notable weakness is identified when dealing with

complicated parts as some regions are not well covered and result in a large volume being left for finishing operations.

Apparently, an attempt to use four roughing orientations seems to be a viable solution in optimizing the roughing process. The method effectively removes the bulk volume of material leaving a reasonable amount for finishing operations. Moreover, this method achieved the highest roughing operation percentage in almost all of the tested models. The implications of this finding is not only limited to reducing processing time, but it also minimises the cutting depth where roughing tool only cut until the centre of cylindrical workpiece. This is a practical solution to prevent the tool travelling to the furthest possible surface that will increase the risk of failure. Considering all these capabilities, the use of four roughing orientations can be denoted as approach to optimize the roughing process in CNC machining.

4 CONCLUSION

CNC machining offers a reliable solution to rapidly manufacturing parts. The current approach using an indexable tool managed to eliminate multiple setups of the workpiece. The visibility program is an effective method to identify orientations for finishing operations. However, performing roughing operations within finishing orientations set tend to constrain the roughing task and caused several inefficiencies. This study overcomes this constraint by formulating an alternative method to find optimum orientations for roughing operations. Implementing four roughing orientations reduced machining time and tool contact length. This approach is considered as a feasible solution to optimize the process. Future work will emphasize coding and programming that operates within the CAD system to create an automatic system to achieve the goal of rapid manufacturing.

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CHARACTERISATION OF THE RELATIONSHIP BETWEEN SURFACE TEXTURE AND SURFACE INTEGRITY OF SUPERALLOY COMPONENTS MACHINED BY GRINDING

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ABSTRACT

The surface texture of a machined component is influenced largely by the processing parameters used during machining and hence, there is a relationship between both the formation of the surface texture and surface integrity of the machined component. In the study to be reported in this paper, GH4169, a hard-to-cut superalloy, widely used in aero-engines, was selected for a detailed investigation into the relationship between the surface texture and the component-performance (surface integrity) of the machined components for which a series of grinding experiments with different grinding-wheels and grinding parameter-values was carried out in order to quantitatively analyze variations of the surface roughness with processing parameters. Further, considering that the features of the ground-surfaces measured are of a random nature, statistic properties of the produced surfaces were revealed and characterised with power spectral density function (PSD) and auto-covariance function(ACV) method respectively.

Keywords: surface texture, grinding process parameters, power spectral density, auto-covariance function.

1 INTRODUCTION

Surface texture, also known as surface topography, is one of the typical surface integrity characteristics for performance evaluation and usually quantitatively denoted by surface roughness parameters such as average roughness R_a , root mean square roughness R_q , ten-point height R_z etc.. Surface integrity provides an effective means for characterizing and assessing the surface and subsurface features and their related functionalities. Different surface texture behaviour will directly cause variation of the surface integrity characteristics and consequent change of mechanical properties of the machined components.

The difficult-to-machine material GH4169, is a kind of nickel base superalloy and widely used in the aerospace and nuclear industry, with its unique combinations of properties such as high temperature strength, high hardness and high heat and corrosion-resistance. However, these exceptional aspects of performance oppositely pose a greater challenge to manufacturing engineers and make it more susceptible to the related manufacturing processes (Ezugwu, et al., 2003). Considering that the surface texture of a machined component is mainly affected by its machining parameters, many researches have been carried out to find their relationship for different

manufacturing processes and materials. For instance, Novovic *et al.* (2004) compared the surface topography and integrity effects on fatigue performance for conventional and non-conventional processed components. Ulutan and Ozel (2011) considered specifically the machining induced surface integrity for aero-used Ti and Ni alloys. Ding *et al.* (2010) studied the creep feed grinding process effect on the grindability and surface integrity of Ni-base alloy when using CBN superhard wheels. Bushlya *et al.* (2012) researched how the turning scenarios will influence the machinability of Inconel 718 components with coated and uncoated PCBN tools. Jawahir *et al.* (2011) analyzed and reviewed the works about surface texture effect on the surface integrity and related functional performance during material removal processes carried out in the last 3 years.

Although the 2D surface roughness parameter R_a , is the most-widely used index and technical requirement for quality of mechanical components, there are other statistical functions which describe specific surface performance more accurately and comprehensively than R_a does. The Auto-correlation function (ACF) is a statistic function describing the space interval over which a correlation or similarity is in the surface profile or texture (Griffiths 2001). It actually tells if the surface studied has repetitive features. The power spectral density function (PSD) decomposes the measured stochastic surface profile into different spatial frequencies and helps identify periodicities. By computing the amplitude of the frequency components that make up the surface, it provides more visual information than single-number parameters like R_a or R_q . Mathematically, the PSD is the square of the Fourier transform of the original surface profile and it can be discretely expressed as follows:

$$PSD(f) = \frac{d_0}{N} \left| \sum_{j=1}^N Z_j \cdot \exp[-i \cdot 2\pi f(j-1)d_0] \right|^2 \quad (1)$$

where $i = \sqrt{-1}$, d_0 the sampling length, Z_j the amplitude function of surface, f the spatial frequency. Auto-covariance (ACV) is the inverse Fourier transform of the PSD data. In an ACV analysis, the measuring system shifts the data laterally and compares it with the original data. The ACV plot indicates how well the shifted surface correlates with the original. This gives a measure of the randomness of the surface.

In this paper, the surface texture and integrity of ground GH4169 components have been studied by using different grinding wheels and processing parameters. Their effects on the surface roughness for the ground components are investigated by single factorial experiments. Furthermore, the random nature of the 3D surface texture is also analyzed with some statistical functions like PSD and ACV, which are able to provide more abundant and visual information for geometry characterization and performance evaluation.

2 MATERIAL AND EXPERIMENTAL PREPARATION

The material researched in this work is GH4169 Ni-base superalloy, the composition of which is presented in Table 1 (Gu *et al.* 2001). Two types of grinding wheels are used within the study for the performance evaluation of GH4169. The first is a conventional single alundum wheel with Al_2O_3 abrasive grains and the second is a superhard CBN wheel with cubic boron nitride abrasive grains. The grit size of these two wheels is 80#. The diameter of the final cylindrical workpieces are 30mm and their length are 100mm. The abrasive debris morphology and ground surfaces of components are measured by using scanning electron microscopy and 3D optical interferometer.

Table 1: The composition of GH4169 superalloy (%)

C	Cr	Ni	Co	Mo	Al	Ti	Nb	Fe
≤ 0.08	17-21	50-55	≤ 1	2.8-3.3	0.2-0.6	0.65-1.25	4.75-5.5	other
Mn	B	Mg	Si	P	S	Cu	Ca	Pb
<0.35	<0.006	<0.01	<0.35	<0.015	<0.015	<0.30	<0.01	0.0005

3 PROCEDURE

Grinding experiments were arranged to investigate the direct influences of wheel property and machining parameters on surface texture and integrity for GH4169 components.

In order to take account of the distinct abrasive grain effects of the grinding wheel on the machined surface texture, a conventional Al_2O_3 grinding wheel and a superhard CBN grinding wheel

are employed to grind the components with the same grinding parameters. Before the grinding tests, the wheels are trued by using a single-point diamond dresser to keep them with the same extent of sharpness. The abrasive debris morphology collected from the two grinding processes are studied and compared with each other by using SEM analysis.

To consider the operational grinding parameters' effect on the surface roughness, two kinds of experiments are designed. Firstly, two components are externally ground with Al_2O_3 wheel at higher and lower material removal rate to determine their respective actions on the machined surface texture. The grinding parameters producing higher material removal rate are $v_s=30\text{m/s}$, $a_p=0.025\text{mm}$, $v_w=10\text{m/min}$, $f_a=1\text{mm/r}$; while the corresponding grinding parameter for lower material removal rate are $v_s=20\text{m/s}$, $a_p=0.005\text{mm}$, $v_w=10\text{m/min}$, $f_a=1\text{mm/r}$. The surface texture of machined components are observed and contrasted by using SEM micrographs. Secondly, a series of single-factorial experiments was designed to separately investigate the variation of surface roughness R_a with the 4 main grinding parameters during the external traverse-grinding with the same grinding wheel and lubrication condition. When one grinding parameter is under study, the others are held constant.

4 RESULTS AND ANALYSIS

4.1 Grinding wheel property's effect

The Al_2O_3 wheel and CBN wheel were used to grind cylindrical components with the same processing condition. As shown in Fig.1(a)-(d), when the Al_2O_3 wheel is used, the debris collected are mostly thin and long strips. They are comparatively uniform and even-proportioned in size. However, when the CBN grinding wheel is used to process the GH4169 component, the size of the abrasive dusts become greater and the debris is extremely irregular the shape, having a semi-lunar appearance. Furthermore, it seems that the debris has been over-pressured, then squeezed, and then torn off from the component's surface, rather than having been normally cut off by the edges of the grains.

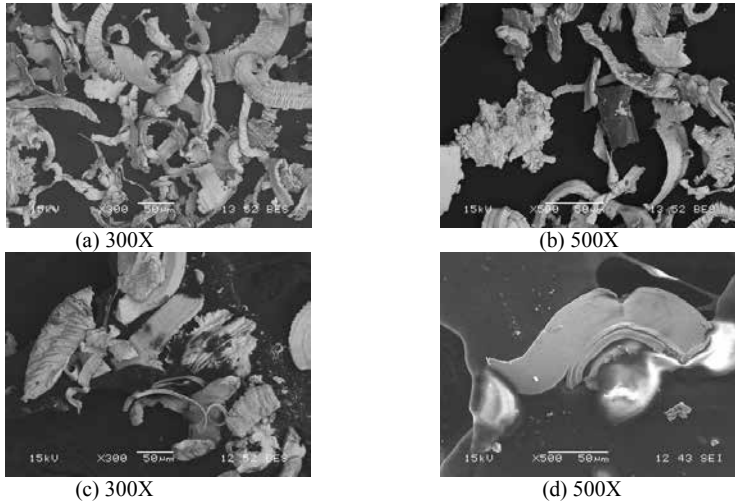


Figure 1: Debris morphology: (a)-(b) removed by Al_2O_3 wheel; (c)-(d) removed by CBN wheel

4.2 Processing parameters' effect

The effect of grinding with different material removal rates with the Al_2O_3 wheel is also investigated. Fig.2 compares the surface texture produced by grinding at higher material removal rate(when $v_s=30\text{m/s}$, $a_p=0.025\text{mm}$, $v_w=10\text{m/min}$, $f_a=1\text{mm/r}$) and lower material removal rate(when $v_s=20\text{m/s}$, $a_p=0.005\text{mm}$, $v_w=10\text{m/min}$, $f_a=1\text{mm/r}$). If the material removal rate is lower, the ground surface is composed of parallel and clear scratches, where the lateral spacing between scratches is around $10\mu\text{m}$.

The walls of scratches are clearly visible and remain integrated even when magnified 2000X. However, if the material removal rate is higher, increased discontinuities, irregularities, defects or deposits, scratches and burrs can be found on the ground surface. There are only a few regular feed marks and at some local areas the machined surface experiences severe plastic deformation and the grinding scratches or lays are smeared and hard to discern: the appearance suggests that some component's material has firstly been ripped off then recombined on the machined surfaces. Many abrasive grains from the Al_2O_3 wheel (see the black particles in Fig.2(g)) are also broken off and attached to the local surface of laps or folds.

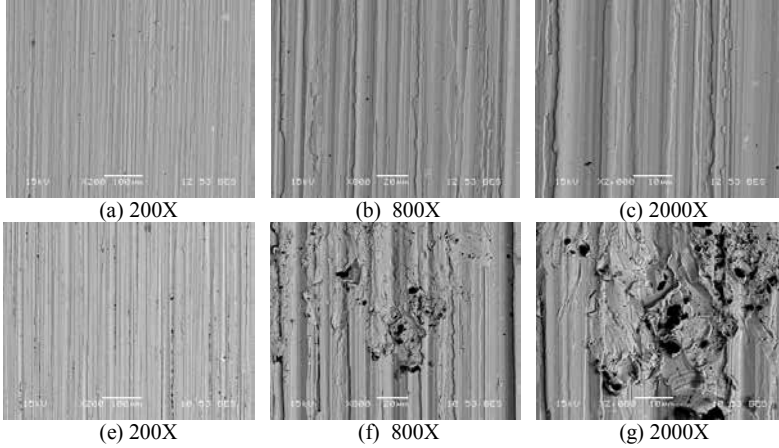


Figure 2: Surfaces ground by (a)-(c) lower and (e)-(f) higher material removal rates

Single-factorial experiments were also carried out to investigate how the surface roughness varies with each main grinding parameter of external grinding. Fig.3(a) depicts that with the increase of workpiece speed v_w from 8m/min to 43.3m/min while other parameters are held constant ($v_s=25\text{m/s}$, $a_p=0.015\text{mm}$, $f_a=1.0\text{mm/r}$), the surface roughness R_a fluctuates slight but takes on a generally declined trend. Fig.3(b) shows that if the feed f_a rises from 0.5mm/r to 3mm/r, the R_a value will increase within the given grinding parameter range. Fig.3(c) demonstrates that the surface roughness R_a drops slowly with the increase of wheel speed v_s from 15m/s to 30m/s. However, it then soars to $0.33\mu\text{m}$ when the wheel speed v_s reaches to 35m/s, nearly twice the value for lower wheel speed $v_s=30\text{m/s}$.

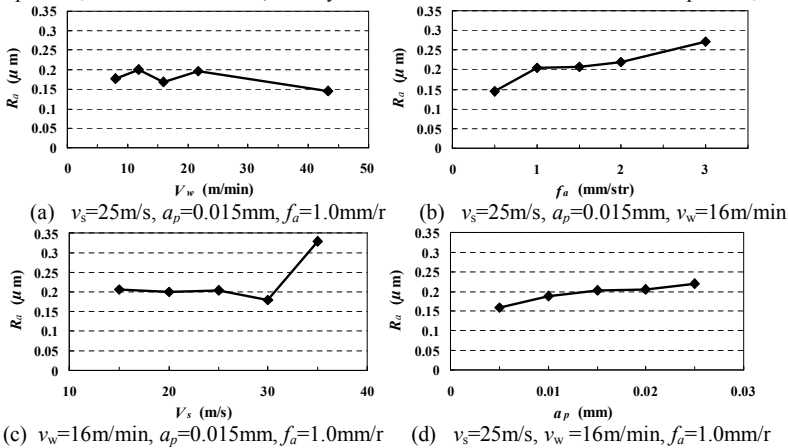


Figure 3: Grinding parameters effect on the surface roughness

The main reason for this abrupt inflexion may be the rapid increase of grinding temperature and force when the wheel speed exceeds a certain value like $v_s=35\text{m/s}$. Fig. 3(d) indicates that with the increase of a_p from 0.005mm to 0.025mm , the surface roughness R_a will increase gradually and monotonously. These results shows that the depth of cut a_p and feed f_a usually maintain a consistent effect on the variation of surface roughness values.

4.3 PSD and ACV analyses of Ground surface

Fig.5 illustrates the measured 3D surface and related 2D profile of component ground with Al_2O_3 wheel at $v_s=25\text{m/s}$, $v_w=16\text{m/min}$, $a_p=0.015\text{mm}$ and $f_a=1.0\text{mm/r}$ by using a 3D optical interferometer. The sampling length is $165.63\mu\text{m}$ and the scanned array are 736×480 . There are traces and lays parallel to the grinding direction X on the 3D ground surface which means the surface takes on periodic and anisotropic features along Y axis to some extent within the measurement range. Fig.5(a)-(b) shows the PSD curve fluctuates to zero as the spatial frequency increase along Y direction, and there are several spikes indicating the ground surface having some finer waveform lengths along with the base wavelength of $\lambda_y=1/f_y\approx 0.05\text{mm}$. ACV is the inverse Fourier transform of the PSD data. In Fig.5(c)-(d), the ACV in the Y direction rapidly declines to and fluctuates around zero, which means the ground surface is less auto-correlated and is of random nature along Y direction.

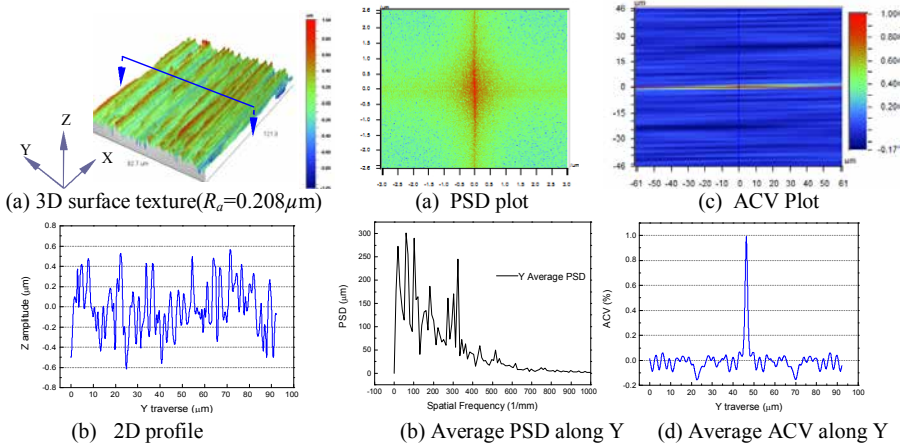


Figure 4: Ground surface topography

Figure 5: PSD and ACV of the measured surface

5 DISCUSSION

The selection of an appropriate abrasive wheel and grinding parameters for a specific workpiece material is vital to the final surface quality of machined components. For the machining-sensitive GH4169 material, it can be seen from Fig.1 that the chips and debris removed by the Al_2O_3 wheel are comparatively thinner and more regular than those removed by the CBN wheel under the same grinding parameters and conditions researched. Actually, the size and shape of the debris indirectly reflect the corresponding precision and behavior of machined surface. It may naturally be imagined that the GH4169 components ground by the Al_2O_3 abrasive wheel usually produce better surface quality and lower roughness than those ground by the CBN abrasive wheel within the grinding parameter range studied. From the point of view of energy input level, it means the plastic deformation during the grinding process with the CBN wheel is more complex and intensive than that with Al_2O_3 wheel, which indicates that the CBN wheel will cause more in-depth and remarkable action on the final machined surface than what Al_2O_3 grinding wheel produces under the identical processing parameters studied.

A large grinding parameter will increase the material removal rate and improve the productivity. For a hard-to-machine material like GH4169, high material removal rate parameters may be readily

employed to speed the machining process and reduce the machining cost. However, a high material removal rate may be prone to cause local areas of the ground surface to suffer severe plastic deformation and endure consequent much higher grinding force and temperature. As Fig.2 shows, the measured mean surfaces roughness ground with lower and higher material rate are $R_a=0.21\mu\text{m}$ and $R_a=0.41\mu\text{m}$. The surface ground with higher material rate has more profound subsurface transformation in addition to obvious surface defect and deformation. This will constitute a potential surface integrity danger for the machined component in service. According to the SEM/EDS analysis, it was found the composition of the black particles in Fig.2(f) are Al and O, so it can be inferred that they are Al_2O_3 grains broken off from the grinding wheel. This may be mainly caused by the rapid increase of grinding force and heat between the interface of the grinding wheel and workpiece when using high material removal rate. This will deteriorate the surface status, lead to high R_a value and makes more abrasive grains break off from the wheel and become attached to the machined surface. To control the surface roughness and integrity of the ground components, the main operational grinding variables are also the key. For the external traverse grinding within the grinding parameters range researched, the results shows that the depth of cut a_p and feed f_a usually have a consistent effect on the variation of surface roughness values.

6 CONCLUSION

This paper presents results in term of surface texture and integrity when grinding GH4169 difficult-to-machine superalloy. Grinding experiments with different grinding wheels and corresponding grinding parameters have been carried out to quantitatively study the effect and variation of surface roughness with specific manufacturing processes. 3D surface texture and its statistical properties like PSD and ACV were observed and analyzed with the white light interferometer technique which further enriches the functional description and characterization of the machined surface. The results give engineers a general guide to the adjustment of grinding conditions and control surface roughness and integrity for the final functional performance when machining superalloy GH4169.

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STATISTICAL ANALYSIS OF THE EFFECT OF MACHINING PARAMETERS ON FATIGUE LIFE OF AEROSPACE GRADE ALUMINUM ALLOY (AL 6082T6)

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ABSTRACT

In this research work, aerospace grade aluminium alloy (Al 6082-T6) was analysed for the effect of cutting parameters on the fatigue life of the machined samples and optimization of cutting parameters for response factor. Different combinations of machining parameters were selected according to the ISO 3685 for sample preparation. Fatigue life of the samples was the response variable under investigation. Specimens for the rotating bending fatigue test were prepared according to the BS ISO 1143:2010 standards. The cutting inserts were selected from Sandvik Coromant catalogue recommended for machining of Al 6082-T6 alloy. A Designed of Experiment (DoE) with full factorial design was employed and a total of 81 experiments were performed for combination of cutting parameters. Fatigue life of the samples was observed to decrease with increasing feed rate, which is attributed to the compressive residual stresses at the surface of the samples. However, fatigue life increased with higher cutting speed and Depth of Cut (DoC).

Keywords: Machining parameters; Aluminium alloy; Fatigue life.

1 INTRODUCTION

Machining is the principal manufacturing process in the world with some 10-15% of the value of all goods being attributed either directly or indirectly to machining (Wyatt et al. 2006). Aluminium based alloys are known for their poor fatigue performance. Fatigue damage occurred in three stages i.e. crack initiation, crack propagation and finally fracture of component (Lee et al. 2005; Suraratchi et al.

2008; Zhao et al. 2008). The surface and subsurface modifications affect the functional performance such as dimensional accuracy of the machined component (Jawahir et al. 2011). Machining played a significant role in producing the high surface integrity of the machined components. Surface integrity affected the crack initiation and propagation stage in the fatigue failure stages. Hence the functional performance of the machined components was improved by improving the surface integrity (Haron 2001; Haron et al. 2005; Ezugwu et al. 2007; Ghanem et al. 2003; Ginting et al. 2009). Surface integrity indicated the surface characteristics such as residual stresses which depend on cutting parameters such as cutting speed, feed rate and depth of cut (Ataollah Javidi et al. 2008). Residual stresses have a significant impact on fatigue life whether it is compressive or tensile (Sharman et al. 2001). Tensile residual stresses which are produced on the surface of the components after machining operation guide to early failure of components (Lin et al. 1991; Elkhabeery et al. 1989; Huafuh et al. 1995; Thiele et al. 2000). Furthermore, high surface quality enhanced and low surface quality decreased the fatigue life of the structures. (Toda et al. 2011). According to research the fatigue life was enhanced by introducing the compressive residual stresses on the surface of the machined component through machining parameters (El-Axir 2002). The parameters such as cutting speed, feed rate and tool nose radius had a large impact on surface quality (Dahlman et al 2004; Arola et al. 2002; Sasahara 2005). This research work focuses on the analysis of effect of turning parameters on the fatigue life of Al 6082 T6 alloy. Samples were machined using different combination of cutting speed, feed rate and depth of cut, including the manufacturer's recommended machining values. Machined samples were then subjected to rotating bending fatigue test and statistical analysis performed for the effect of each parameter on the fatigue performance of the samples.

2 MATERIAL AND EQUIPMENT

Aluminium 6082-T6 alloy was used for fatigue testing in this research work. Specifications of the specimen were prepared by following the rotating bending fatigue test standard BS ISO 1143:2010. The equipment used for fatigue testing experimentation was pure rotating bending fatigue testing machine (Model PQ-6) as show in figure 1. The parallel specimen four points loading was selected from the standard. Dimensions of the specimen are shown in figure 2.



Figure 1: Rotating fatigue testing machine

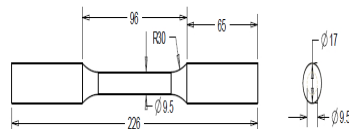


Figure 2: Specimen for fatigue testing.

The inserts (VCGX 16 04 04-AL H10) were selected from the Sandvik Coromant Catalogue 2011 which was recommended for the machining of Al 6082-T6. Each input factor has three levels according to the 3^3 full factorial design of experiment.

3 DESIGN OF EXPERIMENTS

A total of 81 experiments were performed by using different machining conditions with replication of 3. The selected cutting conditions were applied only to the final cut of the specimens. The values for the machining input parameters are shown in Table 1.

Table 1: The values for the machining parameters

S/NO	Parameter	Values
1	Feed Rate (mm/rev)	0.15, 0.2, 0.25
2	Cutting Speed(m/min)	1500, 2000, 2500
3	Depth of Cut (mm)	1.25, 1.5, 1.75

The response factor selected for these experiments was fatigue life of the machined samples and full factorial experiments carried out and analysed.

4 RESULTS AND DISCUSSION

Figures 3 and 4 show the effect of machining conditions on the fatigue life. In Fig. 3, the value used for depth of cut (DOC) is 1.25mm for the machining of testing area of the fatigue testing specimen.

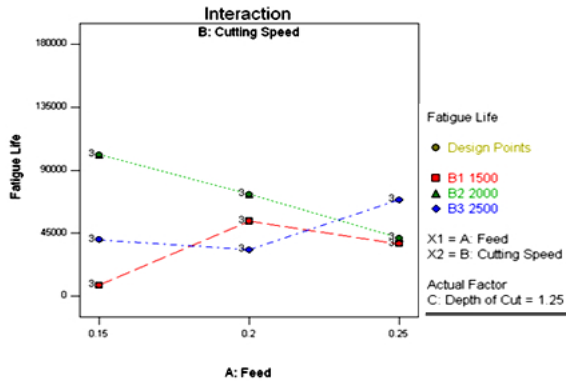


Figure 3: Effect of machining conditions on fatigue life with DOC=1.25mm

It is clear from the figure that fatigue life is more at low feed rate and medium (2000m/min) cutting speed shown by green line. The high fatigue life at the low feed rate could be due to the presence of compressive residual stresses produced at the surface of the machined component. These results resemble the previous research where it was also found that low feed rate enhanced the fatigue life (Sasahara 2005). At the speed of 2500m/min, the fatigue life is more at the higher feed rate (1.75mm/rev) as compared to lower feed rate (1.25mm/rev) shown by blue line. At the cutting speed of 1500m/min, the fatigue life is lower at smaller feed rate (0.25mm/rev) as compared to higher feed rate (0.25mm/rev). So, the fatigue life in case of cutting speed 1500m/min is lower as compared to cutting speed 2500m/min shown in Fig. 3a. At the optimum cutting conditions values (i.e. V_c 2000m/min & $f=0.2$ mm/rev), fatigue life is more with optimum cutting speed and feed. At the cutting speed of 1500m/min, fatigue life is reduced at lower feed rate (0.15mm/rev) as compared to higher feed rate (0.25mm/rev) shown by red line. During the machining of Al6082-T6 alloy, the surface of the machined specimen is improved by applying the higher cutting speed. In the case of cutting speed 1500m/min, the surface quality of the machined component decreases. Such specimens show lower fatigue life as compared to the specimens machined at higher cutting speed. Similar results were also reported by Jeong-Du Kim and Youn-Hee Kang (Kim et al. 1997). At the cutting speed of 2000m/min, fatigue life is more at lower feed rate (0.15mm/rev) as compared to higher (0.25mm/rev) feed rate. At cutting speed 2500m/min, fatigue life is more at higher (0.25mm/rev) feed rate as compared to lower (0.15) feed rate for depth of cut (DOC) 1.25mm.

In Fig. 4a, the response of the fatigue life with DOC=1.5mm in the machining of fatigue testing specimen is shown. The value of depth of cut (DOC) 1.5mm is used for the final cut of the testing area of the specimens. At the cutting speed 1500m/min, the fatigue life is greater at lower feed rate (0.15mm/rev) as compared to higher feed rate (0.25mm/rev) shown by the red line. At the cutting speed 2000m/min, the fatigue life is more at lower feed rate (0.15mm/rev) as compared to higher feed rate (0.25mm/rev). At the cutting speed 2500m/min, the fatigue life is more at the optimum value of feed rate (0.2mm/rev) as compared to lower and higher feed rate shown by blue line. In Fig. 3c, the response of fatigue life with the machining conditions is shown with DOC=1.75mm in the machining of fatigue testing specimen. At the cutting speed 1500m/min, the fatigue life is higher at lower feed rate (0.15mm/rev) as compared to higher feed rate (0.25mm/rev) and there is gradual decrease in fatigue life along the feed rate shown by the red line. At the cutting speed 2000m/min, the fatigue life

is more at lower feed rate (0.15mm/rev) as compared to higher feed rate (0.25mm/rev) and there is gradual decrease in fatigue life shown by the green line. At the cutting speed 2500m/min, the fatigue life is less at the optimum value of feed rate (0.2mm/rev) as compared to lower and higher feed rate.

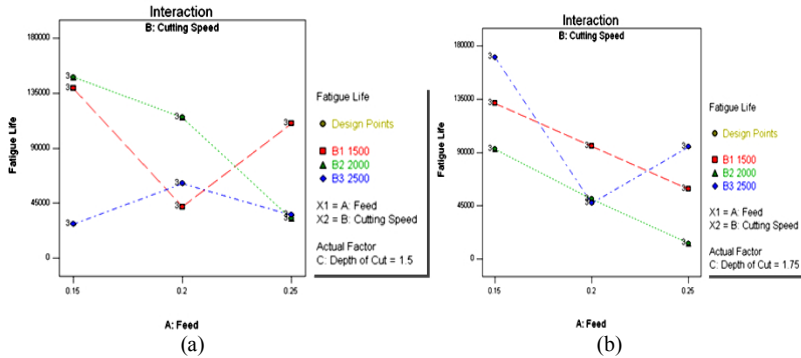


Figure 4: Effect of machining conditions on fatigue life with (b) DOC 1.5mm (c) DOC 1.75mm

As the depth of cut increases from 1.25mm to 1.75mm as shown in Fig.4c, the fatigue life also increases at the same lower feed rate 0.15mm/rev. Due to increases of depth of cut, the compressive residual stresses at the machined surface increases. So, the fatigue life is more in case of more depth of cut 1.75mm as compared to depth of cut 1.25mm. Surface roughness is also more in case of smaller depth of cut 1.25mm as compared to the more depth of cut 1.75mm. Fatigue life decreases as surface roughness increases. So, the longer fatigue life is obtained in case of higher depth of cut 1.75mm as compared to lower depth of cut 1.25mm as shown in the Fig. 3.

5 CONCLUSIONS

- Fatigue life decreases as feed rate increases. Fatigue life is more at low feed rate (0.15mm/rev) as compared to high feed rate (0.25mm/rev).
- Fatigue life increases as depth of cut increases. Fatigue life is more at maximum depth of cut (1.75mm) as compared to minimum depth of cut (1.25mm).
- Fatigue life is more with low feed rate, higher cutting speed and max depth of cut for the values of $f=0.15\text{mm/rev}$, $V_c=2500\text{m/min}$ and $a_p=1.75\text{mm}$.
- There are number of the cutting conditions combinations obtained from the experimental results. According to the desirability of max fatigue life, optimized design variable are cutting feed = 0.15mm/rev, cutting speed = 2500m/min and depth of cut = 1.75mm.

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EXPERIMENTAL AND NUMERICAL STUDY ON SCRATCHING TEST

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ABSTRACT

This paper presents recent investigation of the material removal mechanism in single grit grinding test. Single grit scratches were generated experimentally by using CBN grit on En24T steel and compared with numerical simulation by using finite element modelling (FEM). The material removal mechanism was observed along the scratch length to understand the effectiveness of ploughing and cutting mechanism throughout the scratch. Experiments showed that cutting is efficient at first half of the scratch while ploughing is significantly higher at the second half of the scratch. At the exit side of the scratch almost no material removal takes place. It has demonstrated that FEM simulations match well with experimental results.

Keywords: single grit scratch, ploughing, cutting.

1 INTRODUCTION

Grinding is a material removal process which is widely used in manufacturing industry as a final finishing process. In order to predict and optimise grinding performance, grinding experiments with the support of computer modelling and simulation become increasingly important. The surface generation in grinding is considered as a result of numerous scratches by irregularly shaped abrasive grits which are bonded together forming a grinding wheel. While a grinding wheel consists of numerous of bonded abrasive grits, a single abrasive grit interaction with workpiece can be considered as the most fundamental element in grinding process. Material removal mechanism with the consideration of grit-workpiece interaction was first put forth by Hahn (1962). He proposed that the material removal in grinding consists of three phases which are rubbing, ploughing and cutting. Rubbing occurs at the initial stage of grit-workpiece interaction at very small region including only elastic deformation in the workpiece, while ploughing phase begins with increasing penetration of the grit into workpiece where the material deformation is in both elastic and plastic regions. With increasing of shearing stress at the ploughed material ahead of the grit, material could not withstand without tearing of material in the form of chip removal, and this is called the cutting phase. Rubbing has negligible contribution to material removal, while ploughing play a crucial role in grinding surface creation and energy consumption (Rowe *et al.* 1997). Rubbing and ploughing are undesired mechanism and should be minimised to improve the grinding performance (Ghosh *et al.* 2008). Most researches of grinding material removal were conducted with shaped tools such as diamond indenter, spherical tool, or negative raked cutting tool to simplify the grit shape effect. As a result, scratching with shaped tools gives better agreement with numerical solution such as finite element simulations (Doman *et al.* 2009, Anderson *et al.* 2011), because the modelling is relatively simple. Most researches on scratching focus on the profile of cross section of the cutting path, few investigation has made along the cutting direction.

One of the earliest scratch test was performed by Takenaka (1966) who observed that chip was produced even at small depth of cut (lower than 0.5 μm) in the form of torn leaves from the workpiece surface although rubbing and ploughing phase are prominent in that range of depth cuts. Material removal was found mainly by cutting process when the depth of cut is higher than 1 μm . Komonduri (1971) investigated the grinding mechanism by using highly negative rake angled diamond tool and

observed chip formation up to rake angle of -75° . König *et al.* (1985) investigated that wear types occur on the abrasive grit during the scratching of carbon steel in different heat treatment conditions (annealed, normalized, hardened). It was found that the wear rate is the highest during annealed condition and the lowest during hardened condition. Wang *et al.* (2001) performed single grit scratching test with a conical diamond tool on pure titanium to characterize the material removal mechanism. Focusing material behaviours, they observed that there exist four zones, namely, a stagnant zone, a lamella zone with shear bands, a hardened sublayer zone, and a propagating zone during front ridge development in scratching test.

Klocke *et al.* (2002) developed a 2D FEM model by using Deform software to simulate the single grit cutting process where the grit is passing through the workpiece material. Doman *et al.* (2009) investigated the rubbing and ploughing stages of single grit grinding by using 3D finite element model performed in LS-DYNA software. In the FEM model, the size of the mesh element at the grit-workpiece contact zone was around $10\text{ }\mu\text{m}$. Only rubbing and ploughing stages during single grit grinding were investigated. Depth of cut for the simulation ranged from $1\text{ }\mu\text{m}$ to $20\text{ }\mu\text{m}$. The rubbing to ploughing transition was observed at a depth of cut around $3\text{ }\mu\text{m}$ in the simulation, although in the real tests ploughing was observed at lower depth level. The experimental verification was performed by using an alumina sphere indenter with a diameter of 2 mm . Simulation and experimental results demonstrated a good agreement for force prediction. Anderson *et al.* (2011) investigated the single abrasive grain mechanism by experiment and FEM simulation. Unlike previous work, they used a combined Eulerian and Lagrangian formulation for the FEM model. The 3D FEM model was performed in LS-DYNA hydrocode using explicit time integration. Simulation with a spherical tool only demonstrated ploughing material in front and side of the tool, whereas, a flat nose cutting tool (similar to negative rake angle cutting) produced chips at $4\text{ }\mu\text{m}$ depth of cut. Transition from rubbing to ploughing was not captured, and it was concluded that the three phases of material removal (rubbing, ploughing, and cutting) during abrasive grain cutting seems to occur simultaneously but in different proportion depending on the machining (or simulation) conditions. According to these results, normal forces increased with cutting speed due to strain rate hardening of the workpiece, and tangential forces decreased with cutting speed due to reduction in the coefficient of friction between cutting tool and workpiece.

2 EXPERIMENTAL TEST SETUP

Single grit scratching test was performed on Nanoform250 UltraGrind machine centre. A test setup, shown in Figure 1-(a), was designed and manufactured to accommodate single grit grinding tests. A Kistler 3 axis piezoelectric force sensor was mounted under workpiece to measure forces during single grit scratching. An acoustic emission (AE) sensor was mounted near the workpiece to detect the contact between grit and workpiece. A CBN grit of 40/50 mesh size was used for the scratching test. En24T steel with hardness of 289.2 HV at 1 kg load was used as a workpiece. The workpiece surface was ground and polished to S_a around $0.09\text{ }\mu\text{m}$ prior to the scratching tests. Diameter of the steel wheel was measured as 34.8 mm and a run-out error was less than $1\text{ }\mu\text{m}$. CBN grit was glued onto the circumferential surface of the steel wheel by using Loctite super glue. The workpiece surface was tilted slightly to allow scratches with different depth of cuts. Peripheral cutting speed during scratching was 327.6 m/min . More about description of the scratching process and scratching method can be found in detail in reference (Öpöz and Chen, 2012).

The scratch profile of the samples were measured by using Talysurf CCI 3000 interferometer. A view of 3D profile measurement is shown in Figure 1- (b). After 3D profiles of the scratches were obtained, 2D cross sectional profiles were extracted at every $3.23\text{ }\mu\text{m}$ increment along the scratch length in order to measure the depth of groove, groove area and pile-up area. In the context of this paper, material removal along the scratch path for a single scratch was investigated and compared with FEM simulation. Prominent material removal mechanism is decided using a measure of pile up ratio, which is defined as the ratio of total pile up area to total groove section area in the cross section. The pile up area and groove section area were calculated by using Mountains software (TalyMap universal version 3.1.9).

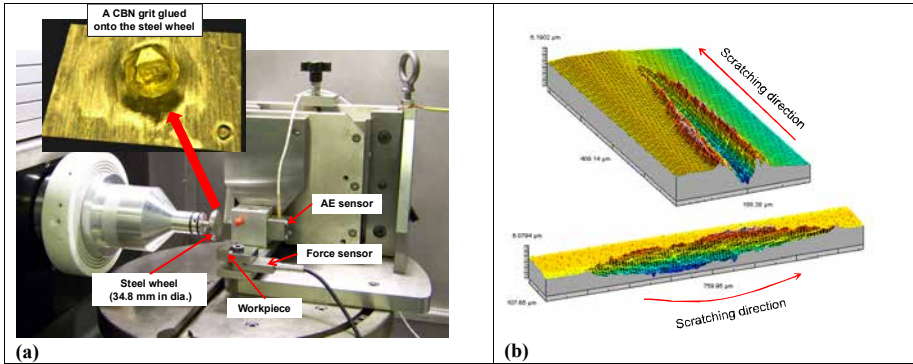


Figure 1: (a) Single grit scratching test setup and (b) 3D cross sectional views of a scratch.

3 FINITE ELEMENT MODELLING

Simplified model of scratch simulations were performed in Abaqus/Standard. Grit simulation path used during simulation is shown in Figure 2-(a). It consist of five steps. Grit speed is not considered and simulation step time is 1 sec for each step, so simulations were performed at very slow speed (100 µm/s horizontal velocity). The workpiece material properties(similar to mild steel) is given in Table 1. Grit was modelled using CBN material properties with Young's modulus $E=909$ GPa, Poisson's ratio $\nu=0.121$, and density $\rho=3400$ kg.m⁻³, in the shape of a half-spherical solid with a radius 100 µm. Remeshing was applied to the workpiece to reduce the element size and increase scratch profile accuracy (Öpöz and Chen, 2011). Element size in the workpiece contact region is less than 1 µm while element size in the grit body is around 4 µm. The grit-workpiece model is shown in Figure 2-(b). Friction coefficients of zero and 0.2 were used to investigate the effect on ploughing mechanism. Total number of elements used in the simulation is 184085. Approximate CPU time for each simulation is 48 hours using a computer with an Intel(R) core(TM) i7 CPU 960 @ 3.20 GHz and 12 GB of RAM.

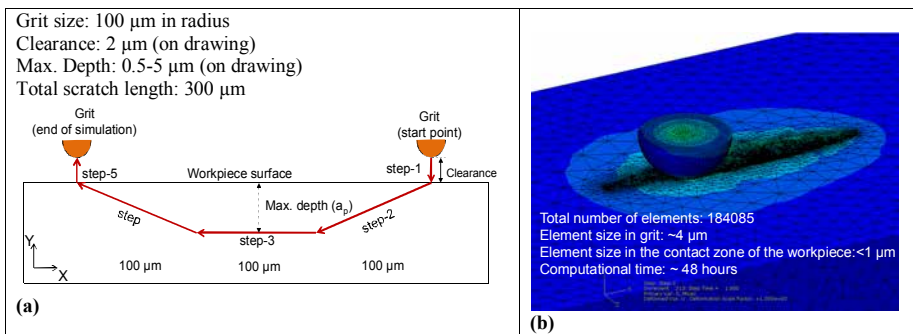


Figure 2: (a) Grit simulation path and (b) FEM model.

Table 1: Material properties used in FEM simulations (similar to mild steel, but smaller yield stress and plastic strain to make deformation more clear).

Mass density (kg/ m^3)	7800
Young's modulus (GPa)	200
Poisson's ratio ν	0.3
Yield stress σ (MPa)	Plastic strain ϵ_p (mm/mm)
180	0
200	0.1
250	0.25
300	0.3

4 RESULTS

4.1 Experimental Results

The pile-up ratio variation along the single scratch is shown in Figure 3, where the point with high cutting efficiency can be found by looking at the lowest pile-up ratio along the scratch length. At the initial stage of grit-workpiece interaction, pile-ratio was found relatively high around 1~3, that shows at that region no cutting occur and only material swelling up due to plastic deformation. Before the ploughing stage, rubbing action may occur but cannot be observed. Pile-up ratio gradually decreases while scratch depth increases towards the deepest point of the scratch. When the scratch depth decreases, the pile-up ratio increases again until the grit-workpiece interaction finishes. While grit is moving towards the end of scratch path, the grit pushes ploughed material forward and some portion of this material could flow along the two sides of the scratch. Therefore, it is apparent in Figure 3 that the pile-up ratio at the exit side of scratch becomes very high even to the range of 10 to 30. Cutting become more efficient with increasing of depth of cut. However, at similar depths of cut, higher pile up ratio was obtained at the exit side of the scratch compared to the entrance side of the scratch. So, it can be inferred that cutting efficiency was decreasing rapidly towards the end of scratch, while it was increasing fast at the beginning of scratch until reaching maximum depth.

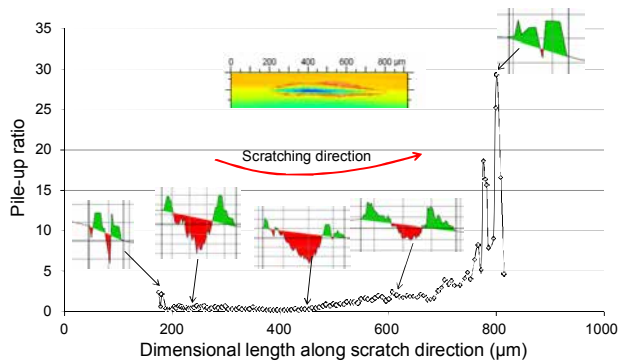


Figure 3: Pile up ratio along scratch length

4.2 Finite Element Simulations

Figure 4 shows the deformation due to grit frictionless scratching with maximum depth of 5 μm . Figure 4 (top picture) shows elastic and plastic deformation during grit-workpiece engagement when the grit was at the end of step-3. At this point, the total deformation in vertical direction including elastic and plastic components is around 5.36 μm , but total deformation at the same location after grit

was moved to the end of the simulation path is around $4.1 \mu\text{m}$. The difference of $1.16 \mu\text{m}$ can attribute to elastic deformation. Figure 5 shows some cross sectional profiles from the approximate location of the middle of step-2, end of step-2, end of step-3 and the middle of step-4 together with calculated pile up and groove area. Figure 6 shows the variations in pile-up ratio along the single grit simulation path. Pile-up ratios gradually increase along step-3 due to material accumulation with the grit advancement. As a result, the deeper the depth of cut, the higher the pile up ratio as seen in Figure 6. However in step-4 there is a dramatic increase in pile-up ratio. This is because the grit climbs up to the end of the scratch simulation. This shows that the ploughing mechanism is completely different in the grit entrance and grit exit during grinding. Simulation results are strongly supported by the single grit scratch tests; see Figure 3. From the observations in the middle of step-4 (at position of $250 \mu\text{m}$ in Figure 6) pile-up ratio increases with increase in maximum depth. In addition, pile-up ratio is also affected by the friction coefficient. It is clear from Figure 6, higher pile-up ratio is obtained with friction.

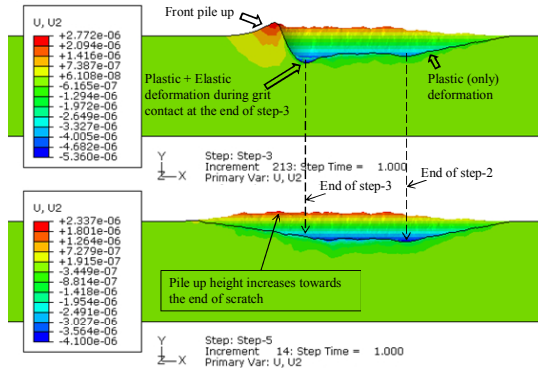


Figure 4: Simulation transactional view along scratching path.

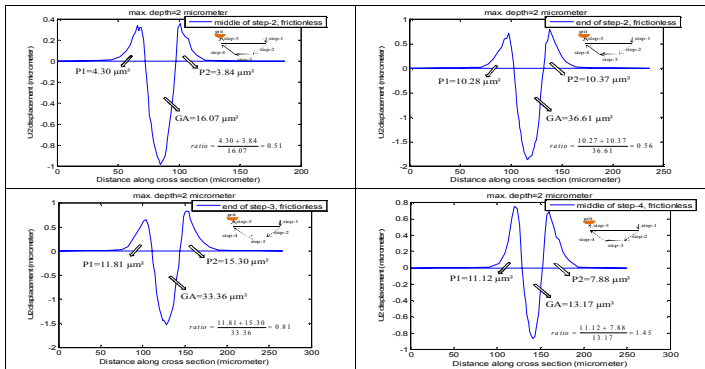


Figure 5: Cross sectional profiles at different location along the scratch path.

5 CONCLUSIONS

Both experiments and FEM simulations support each other in terms of material flow and material removal during the grit scratching. Pile up ratio was proved to be a good measure to illustrate material removal mechanism changes along the scratching direction. It was found that the pile up ratio continuously increases towards the end of scratch after grit passed its deepest cutting depth. At the

exit part of the scratch, very high pile up ratios present and the scratch surface could be above the original surface, which indicates no material removal anymore but the grit may leave ploughed materials on the workpiece surface. Friction contributes to ploughing effect positively. Consequently, cutting is more effective at the entrance side of the scratch until the maximum cutting depth, then becomes less effective dramatically towards the end of scratch. These results will help understanding the differences of material removal mechanisms in the upcut and downcut grinding.

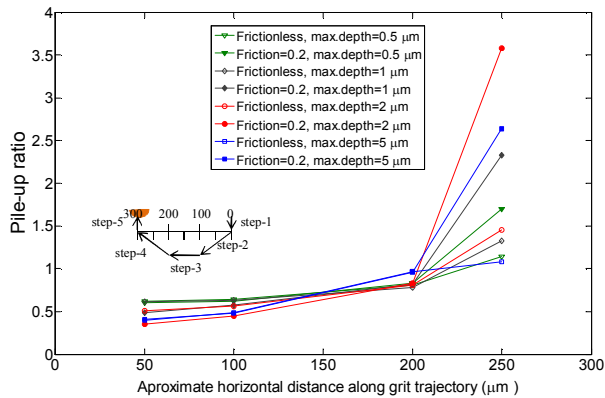


Figure 6: Pile up ratio along the scratch path.

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OPTIMIZATION AND ANALYSIS OF CUTTING PARAMETERS USING CRYOGENIC MEDIA IN MACHINING OF HIGH STRENGTH ALLOY STEEL

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ABSTRACT

In this research, liquid Argon is used as a cryogenic media to optimize the cutting parameters for evaluation of tool flank wear width of Tungsten Carbide Insert (CNMG 120404-WF 4215) while turning high strength alloy steel. Robust design concept of Taguchi L9 (34) method is applied to determine the optimum conditions. This analysis revealed is revealed that cryogenic impact is more significant in reduction of the tool flank wear.

Keywords: turning, liquid argon, flank wear.

1 INTRODUCTION

The adoption of sustainability in machining processes is more an environmental concern than a technical or financial aspect. Still the industry uses various cutting oils /emulsions as cutting fluids, even though they pose environmental and health hazards (Kopac 2009). However, cryogenic gases rapidly evaporate in the atmosphere without leaving any residue to contaminate the environment (Umbrello, Micar and Jawahir 2012). They also have the ability to penetrate rapidly in tool-chip interaction while machining as compared to cutting oils/emulsions (Shaw 1986; Adler *et al.* 2006). In this study, four types of cryogenic methods are to be applied to evaluate the results in machining process namely: (a) Cryogenic pre-cooling the work-piece, (b) Indirect cryogenic cooling, (c) Cryogenic spraying and jet cooling and (d) Cryogenic Treatment

2 CRYOGENIC JET COOLING AND TOOL LIFE

Cryogenic jet cooling is the most effective and economical way to control temperature of tool-chip contact while machining (Yildiz and Nalbant 2008). In flood / spray cryogenic cooling, cutting force is increased which is adversely affected by the life of a tool (Zurecki, Ghosh and Frey 2003). Consumption rate can be made efficient by applying micro nozzles nearby the desired face of a tool (Hong, Ding and Jeong 2001). Concept of sustainability regarding production cost may be achieved

through this way (Hong 1995) and a phenomenon of BUE may be reduced due to low temperature and high pressure developed through jet nozzle (Hong 2001). The cutting temperature of rake & flank face was found to be lower in the case of cryogenic cooling using liquid nitrogen and different cooling configurations (Hong and Ding 2001). About 150 % increase in tool life was reported while cryogenic machining of Steel AISI 1060 through SNMG inserts as compared to dry and wet. (S. Paul, Dhar, Chattopadhyay 2001, Dhar et al 2006). It was also reported tool life has been improved almost two to three times for carbide inserts on steel AISI1040 (Dhar, Paul and Chattopadhyay 2002). Reducing of flank wear by SNMM insert was attributed to its geometric structure having deep grooves parallel to the cutting edges helping entry of larger fraction of the liquid nitrogen jets at the flank surfaces (Dhar, Kamruzzaman 2007; Dhar, Paul and Chattopadhyay 2002).

3 EXPERIMENTAL PROCEDURE

All experiments were conducted using test pieces of Ø85 x 150 mm. The chemical composition is given in Table 1. The samples were normalized at 920°C and maximum hardness was 20HRC. CTX 510 eco Turning machine with tool holder PCLNL 2525 M12 has been used to evaluate the tool life of Sandvik Coromant inserts (CNMG 120404-WF 4215) as per ISO standard 3685:1993(E). Experiments with Liquid Argon have been carried out with an outlet diameter 1.2mm jet nozzle at 4.0 bar pressure. Microscope OPTIKA® at magnification of 20 is used to measure the flank wear width.

Table 1: Chemical composition of alloy steel.

C	Si	Mn	Ni	Cr	P	Cu	V	Mo	S
.27~.32	1.4~1.7	.7~1	<0.25	1~1.3	<.015	<0.25	0.08~.15	.4~.55	<0.01

3.1 Taguchi Method

The robust methodology of Taguchi analyzes the entire parameter space only with a small number of experiments. Orthogonal array L9 (3⁴) is used to analyze the effect of machining parameters with an assumption that no interaction exists between the machining parameters. Machining parameters and their levels are given in Table 2. The experimental layout L9 (34) with responses, mean value of responses and their respective Signal to Noise (S/N) ratio by using eq. (1) is given in table 3(M. S. Phadke 2007). Lower the better type of response is used (Brij *et al* 2012) which is given by the following equation:

$$S/N = -10 \log \left[\frac{\sum_{i=1}^n Y_i^2}{n} \right] \quad (1)$$

Here, n represents the trial conditions and $Y_1, Y_2, Y_3, \dots, Y_n$ represents the values of responses for quality characteristics.

Table 2: Machining parameters and their levels.

Factor Code	Process Parameters	Level 1	Level 2	Level 3
A	Depth of Cut (DOC)	1	1.5	2
B	Feed Rate	0.05	0.10	0.15
C	Cutting Speed (Vc)	220	280	340
D	Cooling Media	Dry	Emulsion Oil	Liquid Argon

Table 3: L9 (3^4) orthogonal array with responses, their means and S/N ratios.

Run	DOC [mm]	Feed [mm/rev]	V _c [m/min]	Cooling Media	Trial 1 VB _B [μ m]	Trial 2 VB _B [μ m]	Mean VB _B [μ m]	S/N Ratio η_i [dB]
1	1	0.05	220	DRY	21.3	30.8	26.05	-28.3162
2	1	0.10	280	ON	16.6	21.3	18.95	-25.5522
3	1	0.15	340	L.Ar	23	22.2	22.6	-27.0822
4	1.5	0.05	280	L.Ar	22.2	23.5	22.85	-27.1777
5	1.5	0.10	340	DRY	30.3	63.3	46.8	-33.4049
6	1.5	0.15	220	ON	26.5	33.3	29.9	-29.5134
7	2	0.05	340	ON	30.3	27.7	29	-29.248
8	2	0.10	220	L.Ar	21.3	12.5	16.9	-24.5577
9	2	0.15	280	DRY	27.3	47.9	37.6	-31.5038

3.2 Selection of Optimal Levels

The main effects of each machining parameters (Tyagi *et al* 2012) at different levels are calculated and given in Table 4. Similarly, the same is graphically represented in Fig.1 by using Minitab15. It is clearly showed that, optimum value can be achieved through applying level $A_1B_2C_1D_3$ (1, .10, 280, L.Ar).

Table 4: Average signal to noise ratio (S/N) for different factor levels.

Process Parameters		Level 1	Level 2	Level 3
A	Depth of Cut(mm)	-26.9835	-30.032	-28.4365
B	Feed(mm/rev)	-28.2473	-27.8383	-29.3664
C	Speed(m/min)	-27.4624	-28.0779	-29.9117
D	Cooling Media	-31.0749	-28.1045	-26.2725

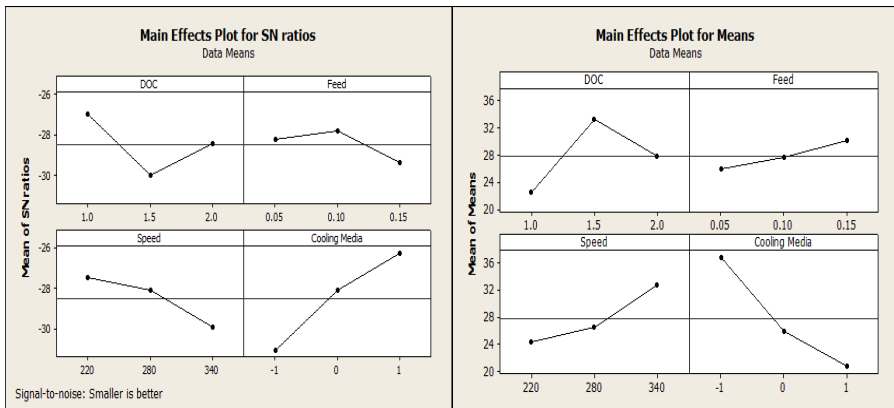


Figure 1: Average values for tool wear.

4 ANALYSIS OF VARIANCE

The purpose of the Analysis of Variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. Results of the Analysis of Variance carried out for the experimental plan is presented in Table 5.

Table 5: Analysis of variance for mean tool flank wear width.

Parameters	DOF	SS	MS	F Ratio	P Value	Contribution%
DOC	2	13.95	6.98	3.72	0.212	22.3
Feed	2	3.76	1.88	-	-	6
Speed	2	9.74	4.87	2.59	0.278	15.5
Coolant	2	35.24	17.62	9.39	0.096	56.2
Residual	0	0	-	-	-	-
Total	8	62.69	31.34	-	-	100
(Residual)	(2)	(3.76)	(1.88)	-	-	

4.1 Estimation of Predicted Mean Tool Flank Wear Width at the Optimal Condition. The estimated S/N ratio η_{opt} using the optimal level of the design parameters (Phadke 2007) can be calculated as:

$$\eta_{opt} = \eta_m + \sum_{i=1}^q (\eta_i - \eta_m) \quad (4)$$

where η_m is the total mean S/N ratio, η_i is the mean S/N ratio at the optimal level, and q is the number of the main design parameters that affect the quality characteristic. Therefore, $\eta_{opt} = -23.7505\text{dB}$, by using eq. (1), we can predict the optimum value of tool flank wear width i.e $11.90 \mu\text{m}$

4.2 Confirmations Run. Confirmation run has been conducted at the achieved optimal level $A_1B_2C_1D_3$ (1, .10, 280, L. Ar). While machining, the maximum tool flank wear width was found to be $13.25 \mu\text{m}$ as shown in Fig.2. The result is very close to the predicted value. The 0.8072 dB improvement in S/N ratio has been achieved. Tool wear is decreased by $3.65 \mu\text{m}$.

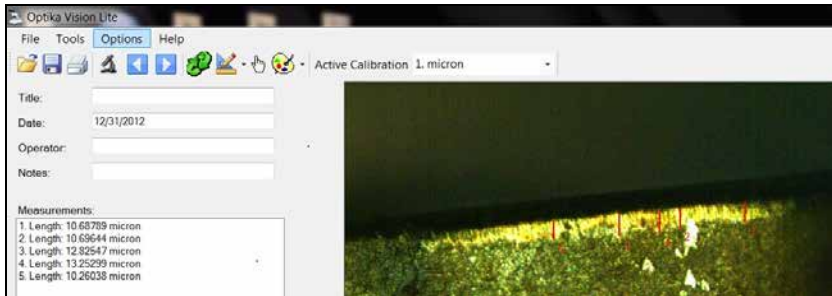


Figure 2: Measurement of tool flank wear.

5 CONCLUSIONS

- Parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the machining parameters.
- The experimental results demonstrate that the *Cooling Media and depth of cut* are the main parameter among the four controllable factors (DOC, Feed, Speed and cooling Media) that influences the flank wear in machining of alloy steel.
- Main effect plots show the significant impact of cryogenic fluid on the tool life. Tool wear is reduced by 43.5% as compared to dry machining and is reduced by 19.9% as compared to emulsion oil.
- Optimal machining parameters $A_1B_2C_1D_3$ (1, 0.10, 280, L.Ar) are recommended to minimize the wear rate. By applying these, the tool flank wear is decreased by 21.8 %

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A NOVEL METHODOLOGY TO ASCERTAIN THE HEATING MECHANISM OF STEEL WIRE DURING ANNEALING IN A TUBE FURNACE

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ABSTRACT

The paper describes a methodology to determine the heating mechanism of steel wire inside a tube furnace used for annealing. The approach is based on Lumped Heat Capacity method of heating where the 'surface heat transfer coefficient' is obtained from radiation considerations. The developed methodology calculates the temperature of the wire as it travels along the tube furnace whose surface temperature is kept at about 800 °C. The results obtained from the developed methodology have been compared with experimental data and the possible reasons for the discrepancies identified. The influence of surface emissivity and its consequence on the heating rate has also been documented. The approach highlights that the method may serve as a useful tool to predict temperatures for this kind of furnace in order to optimize the manufacturing process.

Keywords: annealing, heat transfer, lumped heat capacity.

1 INTRODUCTION

To relieve stresses from cold drawing and to regain ductility, steel wires are annealed in furnaces at appropriate temperatures. The process of annealing is usually accomplished by two methods, either by allowing big coils of steel wires to 'soak' in a controlled furnace environment known as batch annealing (Mehta, 2009) or by continuously feeding the cold-rolled wire through tube furnaces at a controlled speed (Hasan et al, 2012). Prolonged exposure at high temperature accelerates the stress relief and crystal alignment processes such that the final product regains the correct properties for further rolling or for delivery to the customer. In order to ensure a good surface quality, the environment inside the heated furnace is maintained by various non-oxidising gases such as hydrogen or nitrogen (Herring, 2010). In the case of a tube furnace, which is the main concern in this work, the steel wires are fed through a fairly long heated tube maintained at a specified temperature followed by a long cooling section. Figure 1 illustrates the whole rig divided into furnace and two cooling sections and Figure 2 shows a typical temperature distribution of the steel wire as it passes along the rig.

Typically there will be three zones of wire inside the furnace as far as the wire temperature is concerned: the heating zone (increasing temperature), 'soaking zone' (of fairly uniform temperature) and cooling zone (decreasing temperature). In order for the metal crystals to align and for the steel wire to regain the expected yield strength, the soaking zone should be of sufficient duration. When the wire comes out of the tube furnace, a small sample of the wire is checked for tensile strength and hardness. If the required strengths are not met, then the wires are passed through additional annealing operations making the process less efficient and more expensive. A typical wire drawing is completed

in several steps of alternate cold drawing and annealing processes in a series and is very time consuming.

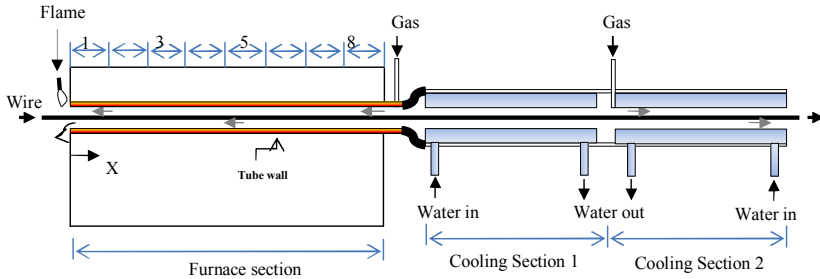


Figure 1: Schematic of an annealing rig for drawing steel wire

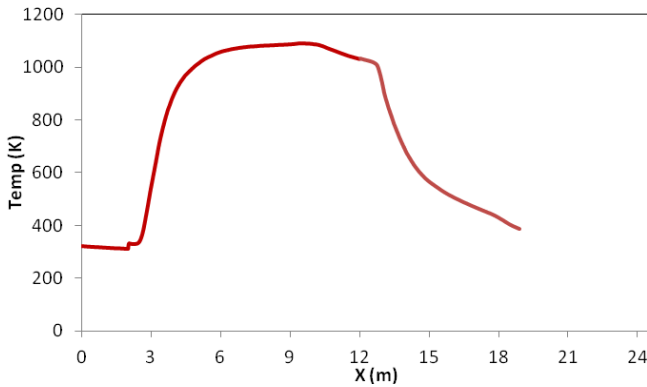


Figure 2: Typical temperature variation of the wire

Clearly, a faulty annealing disrupts the flow of material and means extra work to set new annealing parameters. The net effect means a loss of productivity. The process of tube furnace annealing has evolved essentially by trial and error and rigorous scientific literature on this type of furnace is very limited. On the other hand, batch annealing is suitable for very large production rate, and a considerable attention has been given to these processes and as such a rich volume of literature exists (Mehta, 2009; Perrin *et al* 1988). To highlight the focus of the present work, few relevant issues that came out of the literature are briefly discussed in the next paragraph.

The process of annealing is dependent on the heat transfer from the furnace wall to the core of the wire by radiation and convection through the gases. In the case of batch annealing where the wires are wound in layers, the heat transfer process is further complicated due to thermal contact resistance and air voids. Zuo *et al* (2001) have reported work on the heat transfer for High Performance Hydrogen Bell type furnace and have noted the importance of surface heat transfer coefficient. Regarding the use of reducing gases, the general findings suggest that the use of hydrogen is more efficient due to its higher thermal conductivity than nitrogen. However, hydrogen is more hazardous and hence the installations are likely to be more expensive. An important difference between batch annealing and tube furnace annealing is that the latter has a much higher gas flow rate (Herring, 2010). This also highlights the importance of the fluid dynamics involved in the process. From design considerations, the items of significance are the diameter of the tube, type of gaseous atmosphere, flow rate of gas used, speed of wire and the quality of heating surface. Since the designs have essentially evolved by trial and error, the fundamental thermo-fluidic mechanism is not very well understood. For example,

although the heat transfer is known to be largely by radiation, the relative contribution by radiation and convection are not unclear. An important aspect is the temperature variation within the wire during the heating and cooling lengths.

In this paper a method based on fundamental heat transfer mechanism has been proposed which can act as a tool to predict the heating rate of the steel wire. Some experimental data were collected for steel wire as it passed through the furnace and these data were used for validation. The limitations of the proposed method are also critically discussed.

2 METHODOLOGY

2.1 Experimental Approach

Temperature along the whole length of the annealing rig was obtained by using high temperature thermocouple wires. The junction of the thermocouple was embedded inside a section of a 5 mm stainless steel wire as shown in Figure 3. Temperature readings were recorded by a logger by varying the speed (1 m/min and 2 m/min) and gas compositions of H₂ and N₂. Since the objective of this paper is to concentrate on the theoretical technique, the detailed experimental data are excluded from this paper but will be made available in future. Only one specific case for 100% N₂ and 2 m/min condition is considered for validating the present analytical method.

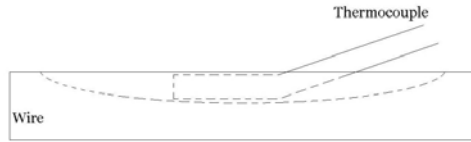


Figure 3: Embedded thermocouple inside the wire

2.2 Analytical Approach

The method is based on the concept of ‘Lumped Heat Capacity’ which is valid for transient heating of convection-conduction system under certain conditions (Holman, 2009). This ‘Lumped Heat Capacity’ is based on the fact that the heat gain in a solid of mass Δm ($=\rho C_p$) is equal to the net heat transfer through the surface area.

$$h(T_{\infty} - T)A_s = \rho C_p \frac{\partial T}{\partial t} V \quad (1)$$

Assuming that the steel wire is split into small lumps (1, 2, 3 etc) as shown in Figure 4, we assume that the heating of each element follows Equation 1 above such that any heat coming from the furnace wall is contributing to the heating of the element through the surface of area, A_s .

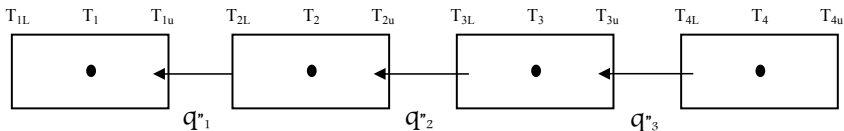


Figure 4: Schematic illustration of the steel wire segments representing the lumps

The symbols used above and their meaning in the current context are given below.

Table 1: Interpretation of symbols in the present context

Symbol	Meaning for lumped heat capacity	Interpretation for the present case
T_{∞}	Surrounding temperature	Surface temperature of tube wall
T	Temperature of ‘lump’	Temperature of wire ‘segment’
A_s/V	Surface area/Volume ratio of lump	Surface area/Volume ratio of segment
ρ, C_p	Density, Specific heat of material	Density, Specific heat of stainless steel
t	Time	Time
H	Surface heat transfer coefficient (convection)	Surface heat transfer coefficient (radiation)

The solution to the above first order differential equation is given below:

$$T(t) = T_{\infty} + (T_0 - T_{\infty})e^{\frac{-hA_s}{\rho C_p V}t} \quad (2)$$

In general, three modes of heat transfer needs to be considered. The conduction component is included in the analysis via q_1'' , q_2'' etc. due to temperature gradients ($T_{1u} < T_{2L}$) as shown in Figure 4 above which is calculated by Fourier’s conduction law given below.

$$q = kA \frac{\Delta T}{\Delta x} \quad (3)$$

The convection component has been found to be negligibly small as reported in our earlier paper (Hasan et al., 2012). The main feature of the present work is that we consider the radiation heat transfer from the tube wall to the steel wire via a radiation surface heat transfer coefficient, h_r which is given by Equation [4].

$$h_r = \frac{\sigma(T_1^4 + T_2^4)(T_1 + T_2)}{2 / (\epsilon_1 + (A_1/A_2)(1/(\epsilon_2 - 1)))} \quad (4)$$

In the above expression, A stands for the surface area and ϵ stands for the emissivity; the subscripts 1 and 2 represent the steel wire and tube wall surface respectively. The h_r replaces h in Equation [2].

With reference to Figure 4, the temperature T_1 of segment 1 at the first time step is calculated via Equation [2], where T_0 is the initial temperature of the wire as it enters into the furnace. At the second time step, when the segment has moved to the next position, temperature T_2 is obtained by reference to T_1 which acts as the initial temperature. The whole process is very similar to the time marching technique used in CFD (Versteeg, 2007).

3 Results and Discussion

The programme has been used to obtain various results and a few representative ones are presented in this paper. Figure 5 shows the analytical results for different speeds of the wire. The experimental data for 2 m/min case is included in the graph for comparison. It can be seen that the faster the wire moves through the tube furnace, the longer it takes to reach the high temperature and thus shortening the soaking length. The differences between experimental and analytical results are not insignificant and may be due to simplifications made in the derivation of the method. For example, the assumption of radiation in a radial plane needs to be scrutinised more carefully. However, the overall qualitative comparison highlights that the method does provide data which is very difficult and expensive to obtain experimentally.

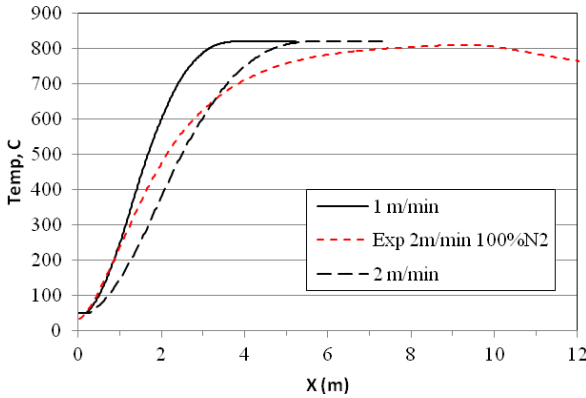


Figure 5: Prediction of heating rate for different speeds

A very important issue that needs highlighting is the influence of surface emissivity, ε which appears in Equation [4]. The ε values can be known for various conditions as found in many references such as Holman (2007). However, for small values of ε , the heat transfer is found to be very sensitive. We have plotted the temperature profiles for various combinations of the emissivity of tube wall and wire surface and only one representative curve is shown in Figure 6. The emissivity of the tube wall is kept at 0.8 because the best estimate is that it is not a smooth surface and is used over a long period of time. On the other hand, the stainless steel is fresh and has a shiny surface as it enters the furnace. However, when it starts to glow inside the furnace its emissivity may vary significantly and no reliable data are available. Our results show that with higher emissivity, the results tend to come closer to the experimental value. From heat transfer considerations, the observations are correct because lower emissivity means higher thermal reflection and hence a slower heating rate.

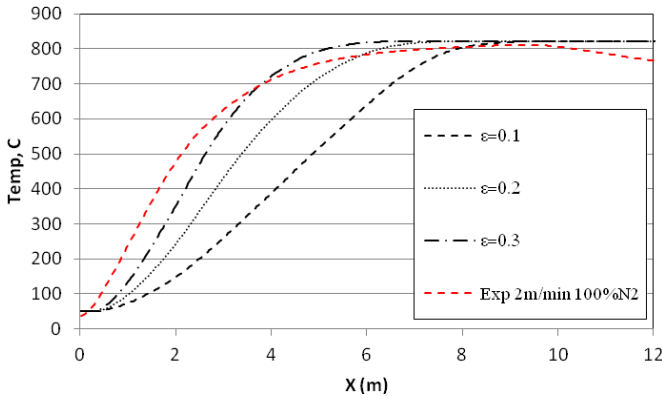


Figure 6: Prediction of heating rate for different emissivity values of wire surface

To analyse further, we have calculated the rate of heating of the wire (calculated for a temperature increase from 100 to 700 °C) and compared with experimental data. The graphs show the interesting similarity between experimental and analytical data and also supports the observations made in the context of the uncertainty associated with emissivity values. These data are deemed to be important

because the realignment of the crystals are known to be dependent on the rate of heating. The data also highlight that the rates of heating are not linear and hence the gross ‘heating rate’ is a gross indication of the process.

Table 2: Rate of heating

Method	Speed/emissivity	Rate of heating °C/sec
Analytical	1 m/min	5.9
	2 m/min	7.1
Experimental	2 m/min	5.8
Analytical	$\varepsilon = 0.1$	4.2
	$\varepsilon = 0.2$	6.5
	$\varepsilon = 0.3$	6.7

4 CONCLUSIONS/FURTHER WORK

The methodology presented in this paper shows good promise to be used as a useful design tool for predicting temperature variations in tube furnaces. However, more work needs to be done to accommodate the following:

- Effect of reducing gas used around the wire.
- Extension of the method to include the cooling section.
- Collect more experimental data to validate the results from the current methodology

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RESEARCH ON FORMING QUALITY OF POLY-WEDGE PULLEY SPINNING

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ABSTRACT

As an important power transmission part, pulleys are widely used in automobile industry, agricultural machinery, pumps and machines. A near-net forming process for six-wedge belt pulleys manufacturing was put forward. For this purpose, the required tooth shape and size can be formed directly by spinning without machining. The whole manufacturing procedures include blanking, drawing and spinning. The spinning procedure includes five processes, performing, drumming, thickening, toothing and finishing. The forming defects occurred during each forming processes of poly-wedge pulley spinning, such as the drumming failure, flanged opening-end, folded side-wall, insufficient bottom size, flashed opening-end, cutting-off bottom, are introduced, and the factors influencing the defects are analyzed. The corresponding preventive measures are put forward.

Keywords: spinning, poly-wedge pulley, forming quality.

1 INTRODUCTION

The poly-wedge pulley is an important part of the belt driving system. The strength, rigidity and the service life of the belt, the efficiency and precision of the driving system are influenced directly by the forming quality of the belt (Pan *et al.* 2007). Pulleys are usually produced by machining after casting or forging, which leads to the disadvantages of material wasting, low production efficiency, low product dimensional accuracy, and poor dynamic characteristics (Packham *et al.* 1978). Spun pulley made by metal sheet is now widely applied in various industrial fields with its high accuracy, energy saving, material saving, good dynamic equilibrium and non-pollution, etc. (Wang *et al.* 1999). For the manufacture of V-pulleys, dynamic dampers and automobile wheels, blanks having cup shape on both sides are required (Packham 1978). A forming alternative for such shapes is a special process of spinning, the so-called splitting process. This is performed by feeding a tapered roller radially into a rotating disk blank. Initial research findings as to conventional splitting are documented by Keller (1996) and Schmoedel *et al.* (2000). For poly-wedge pulley spinning, a thicker blank should be adopted to meet the requirement of tooth forming, which results in the increasing of the material waste and the manufacturing cost. This shortage can be overcome well by thickening process. Various factors may influence the forming quality of spinning based on thickening process. The spinning quality of the poly-wedge pulley not only depends on the accuracy of the shape and dimension of blank, the manufacturing and assembling of tools, but also depends on the setting accuracy of spinning process, processing parameters, and the accuracy of the numerical and hydraulic control system as stated by Sun (2005).

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(4) Tothing: Feeding the tothing roller 3 along the radial direction to form the tooth preliminarily (as shown in Figure 2f).

(5) Finishing: Feeding the finishing roller 4 along the radial direction to shape the tooth accurately (as shown in Figure 2g).

The deformation of the tooth portion of pulley by spinning belongs to the near-net shape forming. The demanded tooth shape and size can be formed directly by spinning without machining. Only slight machining is carried out at the outlines marked by A and B (as shown in Figure 1). Comparing with machining after casting or forging, the material waste was decreased by 50%.

The five processes to form the poly-wedge pulley by spinning complicate the deformation. Different kinds of defects occur during spinning. The main causes and its influencing factors are analyzed and the corresponding preventive measures are put forward.

3 DEFECTS ANALYSIS OF POLY-WEDGE PULLEY DURING DEFORMING STEP BY SPINNING

3.1 Defects during drumming process

The defects occurred during drumming process are mainly diameter expanding at bottom portion, flanging at opening end of workpiece and unsymmetrical drumming (as shown in Figure 3). These defects are actually caused by the previous preforming process. During the preforming process, a desired curvature is obtained by feeding the performing roller 1 along the radial direction together with the upper mandrel downward along the axial direction (as shown in Figure 2c), and the predetermined shallow drum-shaped arc occurs at the side wall of the cup-shaped blank due to the axial pressing of upper mandrel and radial feeding of performing roller 1 (as shown in Figure 2d).

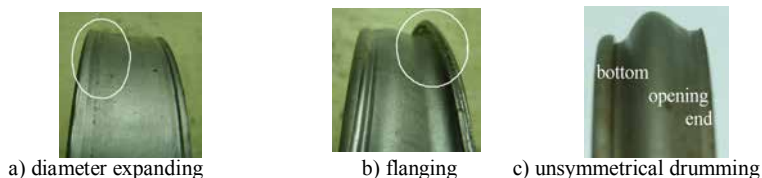


Figure 3: Defects during drumming process

Diameter expanding at workpiece bottom The defect is shown in Figure 3a). The reason for the defect is that the radial feed of roller 1 is too small, the radial feed of roller 1 should be at least 2 times of workpiece thickness, i.e. $4.8 \sim 5 \text{ mm}$ ($(146 - 2 \times (2.55 \sim 2.75) - 130.9) / 2$), where the outer diameter of cup-shaped workpiece $\varnothing 146$ is determined by the maximum outer diameter of part $\varnothing 144.86$ plus the machining allowance 2×0.5 ; $2.55 \sim 2.75$ is variation range of maximum thickness of side wall of cup-shaped workpiece; $\varnothing 130.9$ is the inner diameter of part). If the radial feed of roller 1 is less than 4.8 mm , shallower drum-shaped workpiece will be obtained after performing, drumming deformation at the center portion of cup-shaped workpiece occurs difficultly due to the supporting rigidity of the side wall being strong enough; therefore, diameter expanding occurs at the workpiece bottom because of buckling.

Flanging at opening end The defect is shown in Figure 3b). The reason for the defect is that the setting height of roller 1 is unreasonable. To prevent the metal flowing from the gap Δ_1 between the roller 1 and the surface of the lower mandrel (as shown in Figure 2c), the designed gap Δ_1 should be less than 0.2 , the 8% of workpiece thickness. If the gap Δ_1 is greater than the designed one, under the press of the radial feed of roller 1, the material flows easily from the gap Δ_1 , and results in an unstable deformation of opening end and flanging defect when the upper mandrel moves downward during drumming process.

Unsymmetrical drumming The defect is shown in Figure 3c). The reason for the defect is that the distribution of the side wall thickness of the cup-shaped workpiece obtained by deep drawing is uneven. The thickness reduces gradually from the opening end to the bottom along the side wall of the cup-shaped workpiece (Luo et al. 2010), hence the drum tends to occur at the bottom during drumming.

The main measures to prevent the above defects are as follows: (1) Selecting a reasonable height to set the roller 1, decreasing the gap Δ_1 between the roller 1 and lower mandrel as small as possible on condition that the roller 1 doesn't contact with the lower mandrel, i.e. $\Delta_1=0\sim0.2\text{mm}$. (2) Controlling the radial feed of roller 1 until the arc surface of roller 1 just contact with the side wall of workpiece, i.e. radial feed=4.8~5mm. (3) Controlling the thickness deviation of the side wall of the cup-shaped workpiece obtained by deep drawing strictly, the maximum thickness deviation should less than 7%.

3.2 Defects during thickening process

The defects occurred during thickening process are mainly side wall folding, insufficient bottom size and flash at opening end (as shown in Figure 4).



(a) side wall folding

(b) insufficient size and flash

Figure 4: defects during thickening

Side wall folding The defect is shown in Figure 4a), a swallowtail annular trough occurs on the side wall of workpiece during thickening. The reason for the defect is the unsymmetrical drum during drumming process (as shown in Figure 3c). Because the drum tends to occur at the workpiece bottom and the wall thickness near the bottom is thinner than another portion, the material flows more easily to the bottom than to the opening end of workpiece. Meanwhile, a large resistance force exists at the bottom arc portion, under the action of the pressing forces from both the bottom and opening end directions, the local accumulated material is extruded, which results in the swallowtail annular folding.

Insufficient bottom size and flash at opening end The defects are shown in Figure 4b). The reason for the defects is that the setting height of thickening roller 2 is unreasonable. The gap Δ_2 between the roller 2 and the lower mandrel is greater than the designed one, Δ_2 should be less than 0.2mm, the 8% of workpiece thickness (as shown in Figure 2e).

The radial extrusion occurs on the corner portion A of workpiece (as shown in Figure 1) under the pressing of roller 2, which results in the material flows towards the workpiece center and results in the insufficient bottom diameter. On the other hand, the material at the opening end flows easily towards the workpiece edge from the gap Δ_2 , which results in the flash at the opening end of workpiece.

To prevent the above defects, a suitable setting height of roller 2 should be guaranteed. The gap Δ_2 between the roller 2 and the lower mandrel should be as smaller as possible under the condition that the roller 2 doesn't contact with the surface of lower mandrel, i.e. $\Delta_2=0\sim0.2\text{mm}$. Figure 5 shows a qualified thickening workpiece.



Figure 5: Qualified thickening workpiece

3.3 Defects of bottom cutting-off

The defects of bottom cutting-off may occur during both thickening and toothing processes (as shown in Figure 6). The reason for the defect is that the roundness radius R of roller 2 or roller 3 is too small (as shown in Figure 2e and Figure 2f). Because the thickness reduction at the position C (as shown in Figure 2d) is large during preforming, the bottom cutting-off occurs easily during thickening or

toothing. The problem could be solved well by increasing the roundness radius R from 1 mm to 2 mm. Experimental results showed that roundness radius R should be greater than 0.8 times of the side wall thickness of cup-shaped drawn workpiece.



(a) bottom cutting-off during thickening (b) bottom cutting-off during toothing
Figure 6: Bottom cutting-off

4 TRIAL MANUFACTURING OF THE POLY-WEDGE PULLEY

The experiment was carried out in the HGQX-LS45-CNC vertical spinning machine (Xia et al. 2006). The material of blank sheet is 08Al, the gap $\Delta_1=\Delta_2=0.2\text{mm}$, the radial feed of the preforming roller 1 is 4.8mm.

Figure 7 shows the qualified spun poly-wedge pulley. Figure 7a) shows that the spun pulley has the regular contour, distinct outline and good surface quality. Figure 7b) shows the partial enlargement of pulley tooth. It shows that the tooth profile on the side wall is plump and uniform; the steps on both ends are clear, smooth, properly thick. The inner surface of spun workpiece shown in Figure 7c) is smooth, and fits well with the mandrel; the corner fold between the inner bottom and side wall is trim;



(a) complete outline (b) amplified tooth (c) inner surface
Figure 7: Qualified spun pulley

Table 1 shows the measuring results of the spun workpiece, the measuring items are shown in Figure 1b). The measuring results indicate that the near-net forming process for six-wedge belt pulleys manufacturing put forward in this paper is reliable and economical.

Table 1: Measuring results of spun workpiece

Measuring items	Dimension	Machining allowance /mm	Measuring results	
			No. 1	No. 2
1	$\Phi 144.86 \pm 0.5\text{mm}$	≥ 0.5	148.4	148.6
2	$10 \pm 1^\circ$	/	$9^\circ 30'$	$9^\circ 30'$
3	$R0.3 + 0.25\text{mm}$	/	0.45	0.45
4	1.2mm	/	1.41	1.22
5	17.8mm	/	17.9	17.85
6	$40 \pm 0.5^\circ$	/	$40^\circ 20'$	$40^\circ 15'$
7	$R0.5 - 0.25\text{mm}$	/	0.46	0.46
8	4.5mm	≥ 0.5	5.3	6.14
9	21.5mm	≥ 0.5	22.6	22.7
10	140mm	+0.5	140.1	140.6
11	$141.18 \pm 0.2\text{mm}$	≥ 0.5	141.45	141.45

5 CONCLUSIONS

The defects occurred during poly-wedge spinning are analyzed. The corresponding preventive measures are put forward. The conclusions are as follows:

(1) The defects occurred during drumming are mainly diameter expanding at bottom, flanging at opening end, and unsymmetrical drumming. The defects can be prevented by setting height and radial feed of preforming roller 1, and setting a small thickness deviation of the side wall of the cup-shaped drawn workpiece. The gap Δ_1 between the roller 1 and the surface of the lower mandrel should be less than 8% of workpiece thickness, the radial feed of preforming roller 1 should be about 2 times of workpiece thickness, the thickness deviation of the side wall of the cup-shaped drawn workpiece should be less than 7%.

(2) The defects occurred during thickening are mainly side wall folding, insufficient bottom size and flash at opening end. The folding defect can be prevented by controlling the thickness deviation of the side wall of the cup-shaped drawn workpiece less than 7%; the insufficient bottom size and flash at opening end can be prevented well by a reasonable setting height of thickening roller 2, and the gap Δ_2 between the roller 2 and the lower mandrel should be less than 8% times of the side wall thickness of cup-shaped drawn workpiece.

(3) The defects of bottom cutting-off may occur during both thickening and toothing. The defects can be prevented by increasing the roundness radius R of thickening and toothing rollers properly, the roundness radius R should be greater than 0.8 times of the side wall thickness of cup-shaped drawn workpiece.

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INFLUENCE OF PROCESSING PARAMETERS ON FORMING QUALITY OF NON-CIRCULAR SPINNING

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ABSTRACT

Processing parameters have great influence on forming quality of non-circular spinning. Finite element simulation model of non-circular spinning for the three straight-edge round-corner cross-section (TSRC) hollow-part was established. Variation rules of thickness and springback of TSRC spun workpiece under different processing parameters were obtained by means of orthogonal test as well as the software MSC.MARC. The results show that the influences of the relative clearance ΔC and the feed ratio of roller f_z on the maximum wall thickness thinning ratio δ , are obvious, and the influences of n and D_r are slight; the influences of the nose radius of roller r_ρ on the springback angle $\Delta\alpha$ is the most obvious, and the influences of ΔC and D_r are slight.

Keywords: non-circular spinning, processing parameters, forming quality.

1 INTRODUCTION

Traditional definition of the metal spinning technology is that a continuous and local plastic forming occurs in the blank to form an axis-symmetrical hollow part by means of roller feeding and mandrel rotational movements (Wong et al. 2003). In recent years, a new spinning technology of hollow part with non-circular cross-section is developed (Awiszus 2005). It has the characteristics of high flexibility, high productivity and lost productive cost, and can be used to produce various parts with complex shapes and sizes (Music et al. 2005). Lots of researches proved that comparing with conventional spinning, non-circular spinning has different characteristics in distributions of wall thickness, springback and spinning force, etc (Arai 2005, Awiszus 2011). Awiszus et al. (2005) carried out feasibility test of hollow part with triangle cross-section by a simple spinning device where the radial force provided by spring was taken for constant. The result showed that the thickness thinning rate around junction of bottom and sidewall reached 40%. Cheng et al. (2011) analyzed the thickness distribution of spun hollow part with four arc-typed cross-section. The result showed that the thickness thinning increases with decreasing in the axial feed of roller f_z and the nose radius of roller r_ρ . To study the influence of the main processing parameters on the forming quality of non-circular spinning, the hollow parts with three straight-edge round-corner cross-section (TSRC) which has the typical non-circular feature had been selected as the researched object. The effects of the main processing parameters, such as the roller diameter, roller nose radius, relative clearance between the roller and mandrel, spindle rotational speed and roller feed rate, on the forming quality were obtained based on numerical simulation combining with orthogonal experimental design.

2 MODEL CONSTRUCTION AND PROGRAM DESIGN

2.1 Finite Element Analysis Model

To obtain the influencing factors on the spun quality of non-circular spinning, the TSRC hollow part was selected as the study object (as shown in Figure 1). The part was divided into the straight-side and filleted-corner along the tangential direction, and the bottom-corner, side-wall and opening-end along the generatrix direction. H refers to the height of the part.

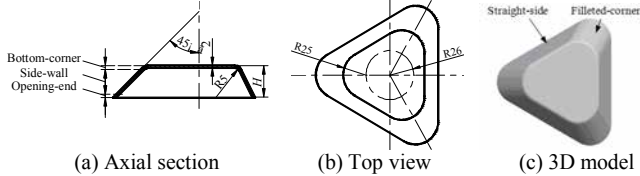


Figure 1: Hollow parts with three straight-edge round-corner cross-section.

As shown in Figure 2, the single pass deep-drawing spinning as stated by Xia *et al.* (2005) with a flat sheet metal blank was adopted, where D_r , r_ρ and β refer to the diameter, nose radius and installation angle of roller, h refers to the forming height during spinning. The blank material was cold rolled steel sheet SPCC with thickness $t_0=2$ mm.

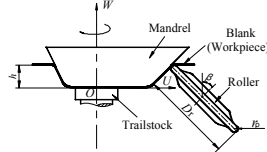


Figure 2: Single pass deep-drawing spinning.

The software Msc. MARC was used to simulate the spinning process. The blank is defined as the elastic-plastic deformation body, the hexahedral element with eight nodes was adopted for the blank meshing. The No.7 element used for large metal deformation was adopted, which is the default element type of software MSC.MARC. The blank is discretized into 8-node hexahedral elements with double layers along the thickness direction (Xia *et al.* 2008), the ratio of the longest side to the shortest side of meshes of all elements is less than 3. The total number of elements is 7282 and the total number of nodes is 14564 in the established finite element analysis (FEA) model (as shown in Fig. 3). The spinning mandrel, tailstock and roller were defined as rigid bodies. The Coulomb friction model is used for the contact between the roller and the blank, the friction coefficient is 0.05 (Liu 2007).

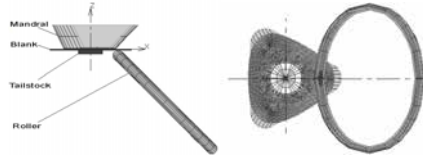


Figure 3 : FEA model of non-circular spinning of TSRC hollow part.

The blank material is SPCC. The mechanical properties listed in Table 1 were obtained by the uniaxial tensile test (Xia *et al.* 2011).

Table 1: Mechanical properties of blank (Xia *et al.* 2011).

Young's modulus E (GPa)	Poisson's rate μ	Stress yield σ_s (MPa)	Tensile strength σ_b (MPa)	Hardening Index n	Strengthening coefficient K
182.9	0.26	218	327	0.22	571.8

2.2 Orthogonal Test Design

As stated by Xia *et al.* (2005), processing parameters influencing the spun quality mainly includes the following items: roller diameter D_r , nose radius of roller r_p , relative clearance between mandrel and roller ΔC ($\Delta C = 100\% (C - t_0)/t_0$, where C is the clearance between mandrel and roller, t_0 is the blank thickness), rotational speed of mandrel n and feed ratio of roller along axial direction f_z (as shown in Figure 3). Five different levels were selected for each factor, and the range of each factor level was based on the results of preliminary experiments. The orthogonal array experiment L25 (5^5) for 5 factors and 5 levels was designed. The simulation schemes and results are listed in Table 2.

Table 2: Factors and levels of orthogonal array.

Levels \ Factors	Roller diameter D_r [mm]	Feed ratio f_z [mm/r]	Relative clearance ΔC [%]	Nose radius r_p [mm]	Rotational speed of mandrel n [r/min]
1	160	0.3	0	5	25
2	200	0.4	-5	7	45
3	240	0.5	-10	9	60
4	280	0.6	-15	11	80
5	320	0.7	-20	13	108

2.3 Evaluation Targets

Thickness uniformity and springback are the important indexes to evaluate the forming quality of spun parts. As shown in Figure 4, define that δ_t is the maximum wall thickness thinning ratio along the intermediate generatrix direction of filleted-corner □ or straight-side □ surfaces ($\delta_t = 100\% \times (t_f - t_0)/t_0$, where t_f is the actual wall thickness of spun workpiece); $\Delta\alpha$ is the springback angle ($\Delta\alpha = \alpha - \alpha_0$, where α is the actual half cone angle of spun workpiece and α_0 is the half cone angle of mandrel).

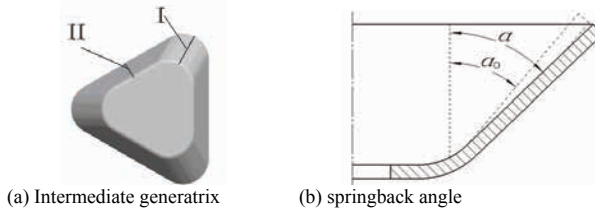


Figure 4: Diagram of evaluation index.

3 SIMULATION RESULTS AND ANALYSIS

3.1 Effect of Five Factors on Maximum Wall Thickness Thinning Ratio

Figure 5 shows the influences of five spinning parameters D_r , r_p , ΔC , n and f_z on the maximum wall thickness thinning ratio δ_t , the vertical coordinate is the mean value of the sum of δ_t of all levels in each spinning parameter, which is defined as the result of the evaluation index and obtained by range analysis (Xuan 2011). Figure 6 shows the relationships between the five factors and δ_t .

Figure 5 shows that the variation tendencies of wall thickness thinning both in surfaces □ and □ are the same, (1) δ_t decreases with the increasing of roller diameter D_r and increases with the increasing of feed ratio of roller f_z . (2) Wall thickness thinning is the most slight when the relative clearance ΔC is -10%, and is the most serious when ΔC is 0; the maximum wall thickness thinning ratio δ_t increases gradually when ΔC increases from -20% to -10%, while decreases obviously when ΔC increases from -10% to 0. (3) Wall thickness thinning is the most slight when the nose radius of roller R_p is 11 mm; δ_t increases gradually when R_p increases from 5 mm to 11 mm, while decreases obviously when R_p increases from 11 mm to 13 mm. (4) δ_t varies slightly with the variation of rotational speed of mandrel n .

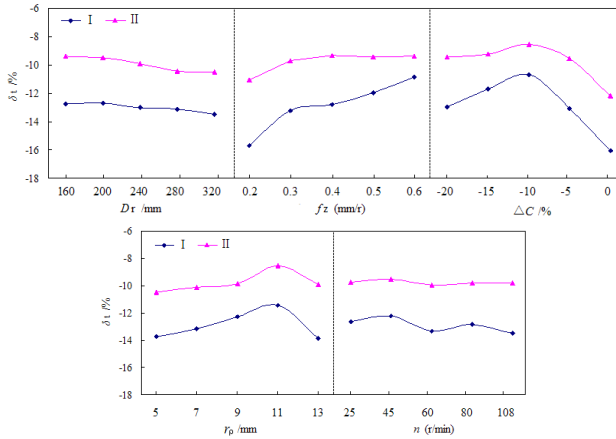


Figure 5: Effects of D_r , r_p , ΔC , n and f_z on δ_t .

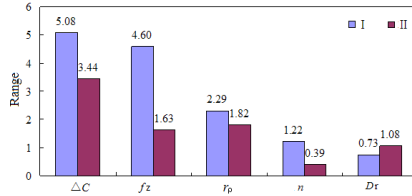


Figure 6: Relationships between D_r , r_p , ΔC , n and f_z and δ_t .

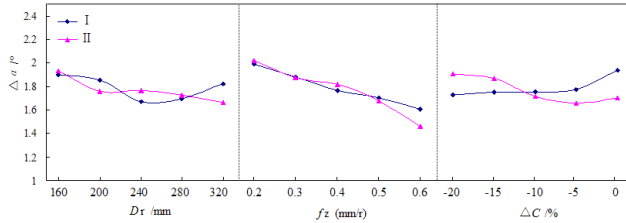
Figure 6 shows that the influences of the relative clearance ΔC and the feed ratio of roller f_z on the maximum wall thickness thinning ratio δ_t are obvious, and the influences of n and D_r are slight; the influence sequence on the maximum wall thickness thinning ratio δ_t is relative clearance ΔC , feed ratio of roller f_z , nose radius of roller r_p , rotational speed of mandrel n and roller diameter D_r .

3.2 Effect of Five Factors on Springback Angle

Figure 7 shows the influences of five spinning parameters D_r , r_p , ΔC , n and f_z on springback angle $\Delta\alpha$, Figure 8 shows the relationships between the five factors and $\Delta\alpha$.

Figure 7 shows that the variation tendencies of springback both in surfacesland II are almost the same, (1) the springback angle $\Delta\alpha$ varies slightly with the variation of the roller diameter D_r and relative clearance ΔC . (2) $\Delta\alpha$ decreases gradually with the increasing of feed ratio of roller f_z . (3) $\Delta\alpha$ approximately linear increases with the increasing of nose radius r_p and rotational speed of mandrel n .

Figure 8 shows that the influences of the nose radius of roller r_p on the springback angle $\Delta\alpha$ is the most obvious, and the influences of ΔC and D_r are slight; the influence sequence on the springback angle $\Delta\alpha$ is nose radius of roller r_p , rotational speed of mandrel n , feed ratio of roller f_z , roller diameter D_r and relative clearance ΔC .



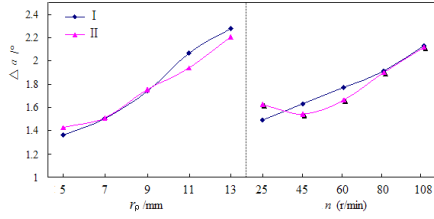


Figure 7: Effects of D_r , r_p , ΔC , n on $\Delta\alpha$.

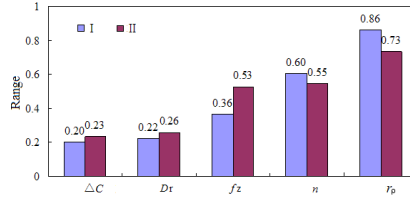


Figure 8: Relationships between D_r , r_p , ΔC , n and f_z and $\Delta\alpha$.

4 EXPERIMENT AND ANALYSIS

The experiment was carried out on the HGPX-WSM spinning machine (Xia *et al.* 2006), the processing parameters used for experiment were the same as the numerical simulation scheme one ($D_i=240\text{mm}$, $r_p=9\text{mm}$, $\Delta C=0$, $n=45\text{r/min}$ and $f_z=0.3\text{mm/r}$), as listed in Table 2. Figure 9 shows the experiment device (Xia *et al.* 2013) and the spun workpiece formed by the experiment.

Table 3 shows the comparison of experimental and simulation results. It shows that the maximum wall thickness thinning ratio δ_i of experimental result is 13.54%, and the corresponding simulation result is 13.03%. The relative error between two results is only -3.77%, which equals $(13.03\%-13.54\%)/13.54\%\times 100\%$. The experimental results conform well with the simulation one. It indicates that the FEA model established in this paper is reasonable and reliable.

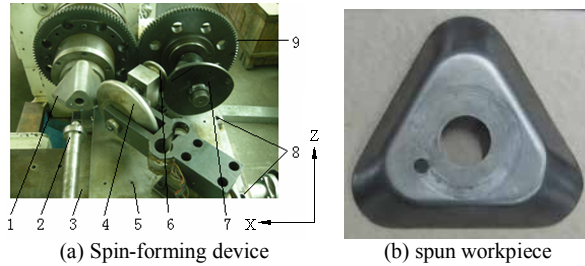


Figure 9: Spin-forming device based on profiling driving and spun workpiece (1-Spinning mandrel, 2-Tailstock, 3-Worktable A, 4-Spinning roller, 5-Worktable B, 6-Profiling roller, 7-Profiling mandrel, 8-Guide strip, 9-Gear).

Table 3: Comparison of maximum δ_i between experimental and simulation results.

Simulation/ δ_i [%]	Experiment/ δ_i [%]	Relative error [%]
-13.03	-13.54	-3.77

5 CONCLUSIONS

The influence of main processing parameters on forming quality during non-circular spinning was investigated based on orthogonal experimental design. The conclusions are as follows:

(1) The variation tendencies of maximum wall thickness thinning and springback along the intermediate generatrix direction of filleted-corner or straight-side surfaces are the same.

(2) The maximum wall thickness thinning ratio δ_t decreases with the increasing of roller diameter D_r and increases with the increasing of feed ratio of roller f_z ; δ_t varies slightly with the variation of rotational speed of mandrel n ; the optimum values of the relative clearance ΔC and the nose radius R_p exit in view of decreasing the wall thickness thinning.

(3) The springback angle $\Delta\alpha$ increases with the increasing of nose radius r_p and rotational speed of mandrel n , but decreases with the increasing of feed ratio of roller f_z ; $\Delta\alpha$ varies slightly with the variation of the roller diameter D_r and the relative clearance ΔC .

(4) The influence sequence on the maximum wall thickness thinning ratio δ_t is relative clearance ΔC , feed ratio of roller f_z , nose radius of roller R_p , rotational speed of mandrel n and roller diameter D_r ; and the influence sequence on the springback angle $\Delta\alpha$ is nose radius of roller r_p , rotational speed of mandrel n , feed ratio of roller f_z , roller diameter D_r and relative clearance ΔC .

ACKNOWLEDGMENTS

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COMPARISON OF THE ENVIRONMENTAL IMPACT OF THE CRIMSON PROCESS WITH NORMAL SAND CASTING PROCESS

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ABSTRACT

The CRIMSON process is an alternative process to conventional casting that can be used for small to medium batch sizes. The aim of this process are to improve the casting quality and reduce the energy consumption within light-metal casting industry. Nowadays, the energy efficiency becomes more and more important. This is not only about the cost of the production, but also about the environmental effect. In this paper, the CRIMSON process will be compared with the conventional sand casting process. The Life cycle assessment (LCA) method will be used to assess the environmental impact of both casting processes.

Keyword: CRIMSON, casting, energy saving, Life Cycle Assessment.

1 INTRODUCTION

The CRIMSON (Constrained Rapid Induction Melting Single Shot Up-Casting) process has been invented by the researchers and engineers from both Cranfield University and a UK company, N-Tec Ltd. The philosophy of the CRIMSON process is to melt just enough mass of alloy in a closed crucible of an induction furnace and to use a counter-gravity filling method to fill a single mould and thus ensure smooth liquid alloy flow behaviour and at the same time avoid unnecessary energy consumption. The process features rapid melting, minimal holding time and counter-gravity filling hence reducing the opportunity for hydrogen absorption and generation and entrainment of surface oxide films. This is a relatively new technology, and thus no previous studies have been reported on the Life Cycle Assessment (LCA) of the process. In this paper, the authors will compare the environmental impact of the CRIMSON process and the conventional sand casting process through LCA simulation.

2 LIFE CYCLE STUDY

2.1 Goal and scope

The principal goal of the LCA study is to assess the environmental performance of the CRIMSON process and the conventional casting process. In contributing to this goal, a tensile test bar is used to assess the environmental performance of both casting processes. The life cycle of the production system of the tensile test bar is a collection of the three life cycle stages which includes: raw material production, manufacturing, and recycling. Because same product is produced by both casting process,

the use phase of the tensile test bar is not included in this LCA. Three impact assessment methods are considered in this study, Gas Protocol, Eco-indicator and Eco-points. All of impact categories are used to assess the environmental impact over the total life cycle.

2.2 System boundaries

In order to provide a clear impact comparison of the CRIMSON process and the conventional process, the system boundaries have been defined for both casting processes. For both casting processes, the material and energy required for each operation were involved. However, due to complexity of the mould making process, the embedded energy was adopted to represent mould making process.

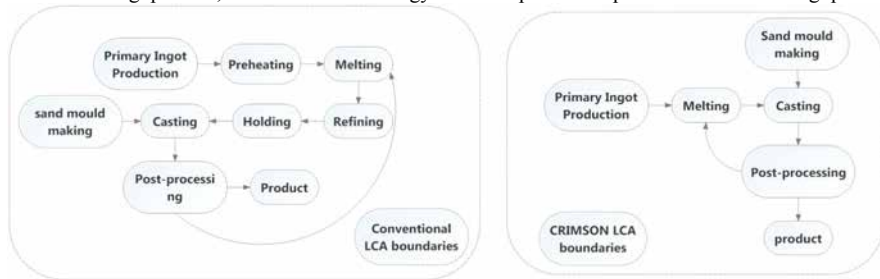


Figure 1: System boundaries for both casting process

2.3 Inventory data collection

Inventory data collection requires production data from cradle to grave. It is the most intensive and demanding task in the LCA. Taking into consideration the system boundaries, the required data for LCA can be identified and collected. The energy and material consumption for primary ingot production were hard to reach. Therefore, the existing LCA simulation package inventory database was used as a source. For sand mould making process, a spreadsheet was developed to measure and estimate the embedded energy. Besides the energy consumption, the spreadsheet also estimates the quantity of the material going through every single process.

3 SIMAPRO SIMULATION

SimaPro is Life cycle assessment software, which is the leading LCA software chosen by industry, research institutes, and consultants (PRe). It has the most complete life cycle inventory database for different industry sectors. For casting foundry sector, following data is available: caustic soda, limestone consumption during alumina extraction; anode, cathode carbon, and aluminium fluoride consumption during electrolysis; inert gas and aluminium additive consumption during ingot casting; energy consumption during entire process and emissions (IAI, 2007). A LCA simulation forms by the assembly and waste scenario. Assembly deals with production stage of the products. It should include all the resources, parts / components and processes to make products. The waste scenario is the use phase and end life of the products. It includes different scenarios such as landfill, recycle, incineration and so on.

3.1 Data input for simulation

The purpose of the analysis is to compare the environmental impact for different casting process. There are four types of models need to be investigated. First model is the conventional tensile test bar casting without recycling, the second model is the CRIMSON tensile test bar casting without recycling, the third model is the conventional tensile test bar casting with recycle, and the last model is the CRIMSON tensile test bar casting with recycle. For non-recycle models, the primary aluminium ingot inventory data was used as metal input; for recycle models, the secondary aluminium ingot from automotive scrap inventory data was used as input.

3.2 Simulation setup

For normal approach, the impact assessment is used to assess the production, use phase, and end life environmental impact of the product. In other word, the normal approach assesses the impacts only related to final products. Clearly, the recycling in this study refers to reuse the high energy content metal removed from fettling, machining, and scrap. It is not simple as reuse the tensile test bar during a end life phase. Therefore, a special LCA model was developed in SimaPro in order to assess the environmental cost of raw material extraction, production, and in-house recycling.

In order to redefine the definition of recycle in SimaPro, a complex model needs to be developed. There are two difficulties to develop such model in SimaPro. First issue is to separate recycled, non-recycled material, and other material. In the normal approach, all material pass through process without any classification. In fact, the material is composed by recyclable material, non-recycle material and others. The second issue is to make SIMAPRO understand each material has a different waste scenario. Once separated the material into different categories, these categories have to be defined with an associated waste scenario. In SimaPro, one assembly has only one corresponding waste scenario. In order to define the different waste scenario to different categories, multiple assemblies are needed.

According to literature (Jolly, 2010), the metal loss during the casting process has been presented in Table 1. The loss in melting, holding, and degassing operations are oxidation and impurities loss. It can be treated as permanent loss. The metal loss during fettling, machining, and inspection are high energy content scrap metal. They can be recycled to reduce the virgin aluminium requirement. Therefore, the raw aluminium input can be divided into three categories: permanent loss, scrapped, and final product, which refers to non-recycle, recyclable, and others.

Table 1: Metal loss during each step of casting operation for the CRIMSON and the conventional casting process

	CRIMSON test bar		Conventional test bar		Loss type
	Weight loss %	weight remain (kg)	Weight loss %	weight remain (kg)	
raw material	0	6.53	0	12.68	Permanent, can be disposed
melting	0.5	6.53	2	12.68	Permanent, can be disposed
holding	0	6.49	2	12.43	Permanent, can be disposed
degassing	0	6.49	5	12.18	Scraped, can be recycled
fettling	60	6.49	77.5	11.57	Scraped, can be recycled
machining	25	2.6	25	2.6	Scraped, can be recycled
scrap	10	1.95	20	1.95	NA
good casting	NA	1.56	NA	1.56	
OME	0.24		0.12		

Beside the metal input, sand is also used to make test bar. Assuming the metal and sand ratio is 1:6 for the tensile test bar sand casting. The sand required for sand mould is 40 kg for the CRIMSON test bar, and 76 kg for conventional test bar. The material input for sand mould also split into two categories: sand can be recycled and sand can be disposed. According to research, 90% of the sand can go back to the process and 10% can be disposed to landfill. Assuming the metal and sand ratio is 1:6 for the tensile test bar sand casting. Based on table 1, the total material input to make casting test bar for both casting process can be categorised as shown in table 2.

Table 2: Total aluminium used to produce the test bar

	CRIMSON Test bar	Gravity test bar
permanent loss (kg)	0.03	1.12
scraped (kg)	4.94	10.01
Tensile test bar (kg)	1.56	1.56
Sand will dispose 10% (kg)	3.92	7.61
Sand will recycle 90% (kg)	35.26	68.53
Total Metal(kg)	6.53	12.69
Total Sand(kg)	39.18	76.14

3.3 The layout of the simulation

After splitting the material flow into different assemblies, the process flow for each assembly can be set up. For permanent loss metal, the process starts from raw material extraction and finish at holding process. For scrapped metal, the process starts from raw material extraction and end at finish process. For tensile test bar, it is the only assembly that goes through whole casting operation from raw material extraction to final shipment. Similarly, the process flow of the sand can be determined. Figure below shows the mind mapping of the simulation.

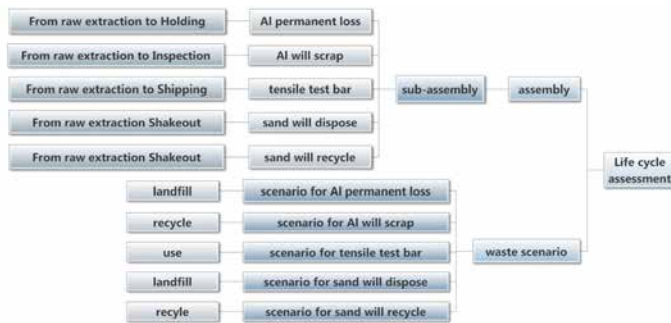


Figure 2: flow chart of new simulation

4 LIFE CYCLE IMPACT ASSESSMENT

4.1 Greenhouse Gas Protocol

The first impact assessment was focused on green house gasses (GHG). The methodology called Greenhouse Gas Protocol has been used to check CO₂ emissions. Table 3 shows the GHG emission to make one set of tensile test bar. Table 3 also shows the emission results calculated from the author's spreadsheet. Ignoring the limitation of the spreadsheet (lack of data about early raw material extraction, therefore embedded energy was used), the spreadsheet results and the simulation results are considerably close.

Table 3: the CO₂ emission result from the simulation and the spreadsheet.

process		spreadsheet (kg)	simulation (kg)
non-recycle	CRIMOSN	88	108
	Conventional	172	210
recycle	CRIMSON	25	33
	Conventional	53	62

4.2 ECO-indicator

Besides the CO₂ emission assessment, various environment impact assessments can be achieved by using SimaPro simulation package. In this project, two more LCA methodologies have been used for comparing the environmental impact of the conventional casting process and the CRIMSON casting process. ECO-indicator 99 HA was the first method adopted to assess the life cycle impact. It expresses the emissions and resource extractions in 11 different impact categories (Salonitis et al, 2006) and (Drakopoulos et al, 2009).

Total cumulative impact results are shown in figure 3. From the figure, the total environmental effect for each casting scenario can be seen. First of all, recycle sand and metal can reduce the environmental impact for casting process. 62% of impact can be reduced after recycling for the CRIMSON process, and 60% of impact can be reduced for the conventional process. Besides the influence of the recycle activity, the main purpose of the simulation is the comparison of the

CRIMSON process and the conventional cast process. From the result, no matter recycle activity applied or not, the CRIMSON process has less impact than the conventional casting process. 49% and 47% of impact can be reduced for non-recycle and recycle activity respectively.

The impact caused by individual process such as sand mould making and casting production also can be seen from the simulation result. Right side of Figure 3 is the environment impact contribution for each production processes.

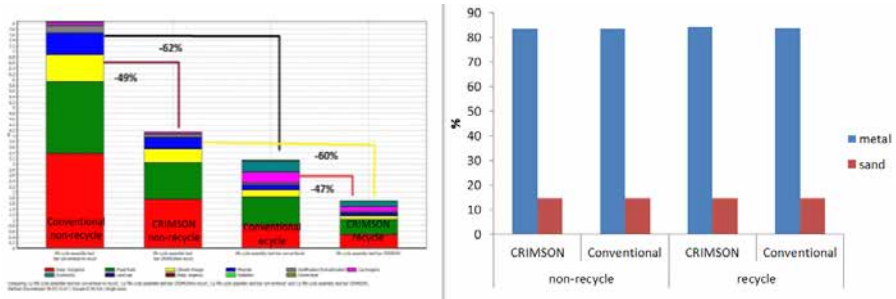


Figure 3: ECO-indicator single score results for four casting scenario

4.3 ECO-points 97

The ECO-Points 97 is the second method used in impact assessment. It is based on actual pollution and on critical targets that are derived from Swiss policy (SimaPro). This means that the emission results are compared with the target values set by government (Konstantinos Salonitis, 2006). After the weighting factor is applied, the comparison of the CRIMSON process and the conventional casting process is shown as below. From the table 6, it can be seen that the major contributor the environmental pollution are the NO_x, the SO_x, NMVOC, the NH₃, Dust PM₁₀, and CO₂. Furthermore, these gases are the resource for global warming.

Left side of Figure 4 is the single score for four casting scenarios. Again, the recycle activity reduces the environmental pollution about 55%. As it can be seen for the comparison between the CRIMSON Process and the conventional casting process, it has similar results like ECO-indicator. Same as ECO-indicator, the impact caused by individual process such as sand mould making and casting production also can be seen from the simulation result. Right side of the Figure 4 is the environment impact contribution for each production processes.

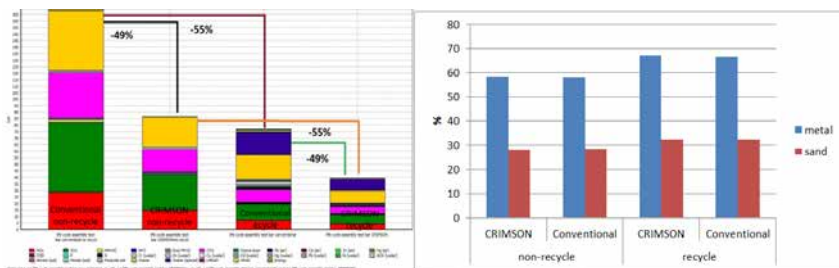


Figure 4: ECO-point single score results for four casting scenario

5 DISCUSSION

It was found that the CRIMSON process has less impact compared with the conventional casting process. In fact, no matter which impact assessment method is used, the environmental impact for the CRIMSON is about half of conventional one. Such result is quite interesting because it match with the metal input as table 2 shows. It means that the environmental impact is mainly influenced by the

metal input. In fact, this should be expected because the aluminium data used is the primary ingot produced in plant. In reality, such production includes a refinery, a smelter and an ingot casting plant. Compared with ingot production from bauxite, the resource and energy input to make tensile test bar is very insignificant. According to evidence shows in SimaPro inventory database, the secondary production only account for 2% of primary production energy consumption. Therefore, the impact results are mainly influenced by the amount of primary ingot input

Furthermore, if we investigate why metal input are different for both casting process. It can be found that everything is related to Operational Material Efficiency (OME). The OME for the CRIMSON and the conventional process are 23.9% and 12.3%. Therefore, the CRIMSON process only use half of metal to produce same casting compared to conventional process (table 2). The associate energy consumption also halved. Meanwhile, because of the OME, the sand demand and associate process energy for CRIMSON process also halved (table 2). Since all of the input data for the CRIMSON process were halved, its environmental impact also halved.

6 CONCLUSION

In reality, the materials that go through the casting process are not split. However for the purpose of investigating recycling influence, it is useful to split the material flow as table 2 shows. This ensures alumina and dead sand send to landfill, scrapped metal and reusable sand send to recycle, test bar send to customer. The difficult of modelling recycle model is solved. Mind mapping shows at figure 3 is the logic of the simulation model. Each sub-assembly has its process input and resource input according to the data shows in table 2. Gathering all the sub-assemblies, the Life Cycle of the casting process can be assessed.

In this paper the LCA methodologies have been used for comparing the environmental damage of the CRIMSON process and the conventional casting process. Because of the operational material efficiency, tensile test bar made by the CRIMSON process only use half metal compared with the conventional process. Furthermore, because the metal input reduced, the corresponding sand, energy and other consumables also reduced. Therefore, the CRIMSON process only has half of the environmental impact compared with the conventional process.

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STUDIES ON FATIGUE BEHAVIOUR OF WELD-BONDS OF Al-Mn-Mg ALLOY

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ABSTRACT

In the present paper, fatigue and metallurgical behaviour of weld-bonds and adhesive bonds developed using 2 mm thick aluminium alloys namely 5052 alloy have been reported. Weld-bonds were prepared using structural adhesive (Epoxy resin) and spot welding (20 kA welding current for 6 cycles welding time at welding pressure of 0.5 MPa). Curing after applying Epoxy resin for developing adhesive bonds and weld bonds was performed at a temperature of 100 °C for 90 min. Fatigue tests were conducted under tension–shear loading pattern with stress ratio of 0.5 and loading frequency of 5 Hz. The maximum tensile shear load for fatigue test was kept at different level i.e. 90%, 80%, 70% and 50% of the ultimate shear tensile strength of weld bond and adhesive bonds. The fatigue lives of both adhesive bond and weld-bond joints decreased with increase in maximum tensile shear load. Fatigue performance of weld bond was higher than adhesive bond especially at high load.

Keywords: 5052 Aluminium alloy, weld bonding, mechanical properties.

1 INTRODUCTION

The engineering systems such as cars and aircrafts have variety of joints including spot welds. These joints are invariably subjected to fatigue loading during the service. Efforts are continuously being made by technologists to enhance the fatigue performance of spot weld joints using different hybridization approaches spot weld-solder/braze joint, spot weld-adhesive joint etc (Long et al. 2008, Goncalves et al. 2006, Chang et al. 1999, Wang et al. 1995). A combination of spot welding and adhesive joining is called *weld-bonding*. Recently some work has been published on fatigue behavior of weld bonds on steel and aluminium alloys. Long et al. (2008) studied fatigue properties and failure mode of spot weld and weld bonds of high strength steels and reported that weld bonds show significantly higher fatigue strength than spot weld especially at low load condition (high cycles fatigue). Goncalves et al. (2006) reported higher ultimate load and displacement for weld bonds than adhesive bonds and spot welds. Chang et al. (1999) reported fatigue behavior and fracture characteristics of three types of joints and showed that the application of adhesives in spot welding greatly improves the fatigue performance of the joint, while the presence of weld spots in adhesive-bonding has a negative effect on the joint fatigue performance. Wang et al. (1995) investigated the failure behavior of the weld-bonded aluminum joint and found that adhesive bonds offer slightly higher fatigue performance than weld-bonded as presence of resistance spot weld decreases the fatigue strength. Further, the fatigue performances of spot welds of aluminium and steel were reported to be much lower than the respective weld bonds. Buddle et al. (1992) reported that the weld bonds show slightly longer fatigue life as compared to adhesive bonds. Further, the limiting range of stress for weld bond was found to be much superior to spot welds. The literature on fatigue studies of weld-bonds of Al-Mn-Mg aluminium alloy (AA 5052) is very scant therefore, in this study, an attempt has been made to investigate the fatigue and metallurgical characteristics of weld bonds of 2 mm thick Al-Mn-Mg aluminium alloy (AA 5052 H32).

2 MATERIALS & METHODS

A weld-bonded joint is composed of spot weld nugget, the heat-affected zone (HAZ), base metal and the adhesive layer, each with different microscopic compositions. The schematic of weld bond joint is shown in Fig. 1. The chemical composition of the 5052 H32 aluminum alloy and properties of resin and hardener used for adhesive bonding are shown in Tables 1 and 2.

Table 1: Chemical composition (wt%) of Al 5052 H32 used in present work

Si	Fe	Cu	Mn	Mg	Cr	Zn	Balance
0.15	0.33	0.03	0.07	2.68	0.1	0.03	Al

Table 2: Properties of adhesive selected

Material	Viscosity (Pa)	Relative density (g/cm^3)	Max. working time min.	Mix ratio (R/H)	Thermal conductivity $\text{W/m}^0\text{C}$	Average thermal expansion coeff. K^{-1}
Resin (R)	24-45	1.15-1.25	20	50:50	0.22	23.6×10^{-6}
Hardener (H)	20-30	0.94-0.98	min. after mixing			

Adhesive was composed of resin (bisphenol epoxy) and hardener (mixture of polyaminoamide and aliphatic polyamine). The weld bonds of the aluminium alloy (5052 H32) sheet of size $100 \times 25 \times 2 \text{ mm}^3$ were developed using following steps (Mittal, 2012) and the same has been exhibited shown in Fig. 2. The test specimens of adhesive bond were prepared with overlap length of 25 mm. Surface of aluminum sheet was roughened with 220 emery grade paper. Spot welding was performed using welding current of 20 kA, welding time of 6 cycles, and welding pressure of 0.5 MPa after applying adhesive samples. Thereafter, curing was done at 100°C for 90 minutes. All weld-bonds were tested after 72 h of curing. Standard metallographic procedure was used for preparation of samples for microstructure study. The polished specimens were etched using a solution of 5% diluted hydrofluoric acid (5 ml HF, 95 ml water). The micro structural studies of the weld were carried out under an optical microscope. The microhardness testing of the weld-bond specimens was carried out using Vickers micro hardness indentation at a load of 50gms or 490.3mN. The hardness of HAZ was studied at a distance of about 0.1 mm from the fusion boundary in weld-bonded joint. The hardness was measured in two directions a) major axis and b) minor axis of elliptical shape nugget of weld bonds (Fig. 3). The fatigue-shear tests were carried out in hydraulically operated dynamic universal testing machine. The fatigue tests were performed in terms of different percentages of the ultimate shear tensile load at fracture. Values corresponding to 90%, 80%, 70%, and 50% of this load (in accordance to ASTM D3166 specifications) were complemented with additional values at 60%, 40% and 30% for a better characterization of the fatigue response at low levels of loading. The fatigue loading was performed at constant load ratio $R (L_{\text{max}}/L_{\text{min}})$ of 0.5 at loading frequency of 5Hz for all the tests. Complete separation of the test piece (for adhesive-bonded and weld-bonded joints) was considered as failure. The fatigue life as the number of cyclic loading to fracture of the specimens was obtained at different maximum shear loads. The results reported in this work are valid at room temperature only because the adhesive layer tends to get damaged when exposed either to high temperature or humid atmosphere.

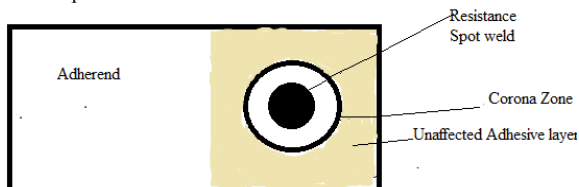


Figure 1: Schematic of weld bond joint.

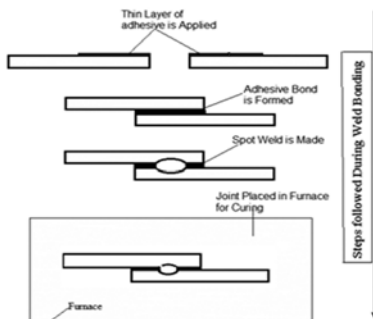


Figure 2: Schematic representation of steps in weld-through technique of weld bonding (Mittal et al. 2012)

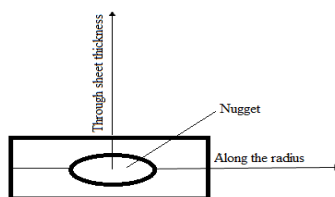


Figure 3: Schematic diagram showing direction of hardness measurement from the centre of the weld nugget of weld bond

3 RESULTS & DISCUSSION

3.1 Microstructure

The micrographs of the different location in weld nugget of weld-bond prepared using welding current of 18 kA, weld time of 6 cycles and welding pressure of 0.5 MPa are shown Fig. 4 (a-c). The microstructure of base metal depicted alpha aluminium and second-phase particles in aluminium matrix (Fig. 4 a). The heat affected zone exhibited coarser grain structure than base metal and weld nugget (Fig. 4 b). At the centre of weld nugget, fine dendritic structure was observed while columnar dendritic structure was noticed near the fusion boundary as shown in Fig. 4 (c). These observation are in agreement with Cross et al. (1994) as it was reported that in general the microstructure of spot weld metal of the non-heat-treatable alloys i.e. 5xxx alloy is composed of columnar, epitaxial grains with a cellular or columnar-dendritic substructure with inter-dendritic eutectic constituent i.e. Mg_3Al_2 . Apart from the above common micro-constituents observed in weld metal and base metal Al-Mg-Mg alloy, weld nugget of weld-bonds also exhibited inclusions (Fig. 5). These inclusions develop primarily due to entrapment of by-products produced due by thermal decomposition of adhesive during spot welding. The heat affected zone around the weld nugget showed coarsening and recrystallization due to weld thermal cycle experienced by the base metal during spot welding. There changes are expected to cause softening of heat affected zone in weld bonds of Al-Mn-Mg alloy.

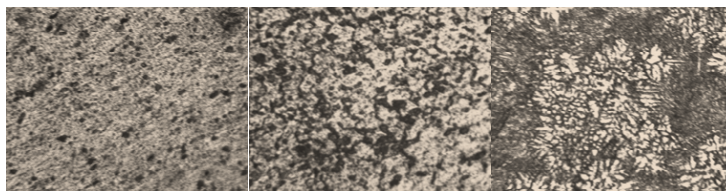


Figure 4: Optical micrographs of the different location of weld-bond a) base metal, b) heat affected zone and c) fusion zone (100X)

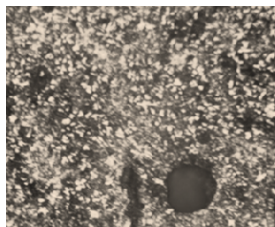


Figure 5: Macrograph of weld nugget of weld-bond inclusion due to present of adhesive (100X)

3.2 Microhardness

The hardness in the weld et zone of weld bond was measured in two directions one along the radius of the nugget (major axis) and the other along the sheet thickness (minor axis) and results of the same are shown in Fig. 6(a, b). The hardness at the centre of the weld nugget was found to be approximately same as that of the base metal. On approaching from weld nugget centre towards the fusion boundary reduction in the hardness of weld nugget was observed. This variation in hardness is attributed to difference in grain structure of the weld near fusion boundary and at the centre of the weld nugget. Finer grain structure at centre of weld nugget results in higher hardness than that near fusion boundary. The dissolution of magnesium and manganese in alpha aluminium matrix is expected to increase the hardness of HAZ by solid solution strengthening. However, coarsening of the aluminum grain would be having opposite effect on the hardness of HAZ.

Study of the variation in hardness of weld bond developed using different combination of spot welding parameters also showed similar trend of variation in hardness of weld nugget zone, HAZ, and the base metal. However, weld bonds were found to differ in respect of spot weld nugget diameter, depth of fusion and width of HAZ. It has been reported that the width of HAZ becomes greater for spot weld than weld-bond of Al 6061 (ASM handbook 1994). This is attributed to that fact that the presence of adhesive layer in weld-bonds reduces heat conducted from weld to base metal because thermal conductivity of aluminium ($180 \text{ W/m}^\circ\text{C}$) is much higher epoxy adhesive ($0.22 \text{ W/m}^\circ\text{C}$).

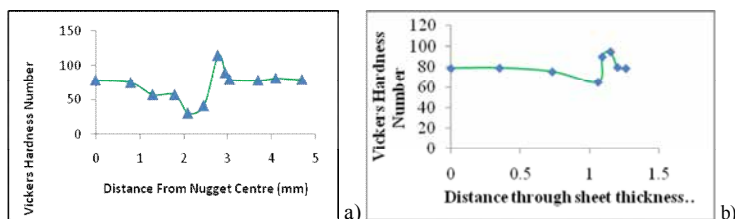


Figure 6: Variation in hardness of weld bond from center of weld nugget in direction of a) major axis and b) minor axis

3.3 Fatigue Testing

The fatigue performance of the adhesive bond and weld bond is shown in Fig. 7 (a-b) and Table 3.

Table 3: Fatigue tests experimental results for adhesive bonding and weld bonding

Joint type	Number	Stress Ratio	Maximum Load (% of USTL), (KN)	Minimum Load (KN)	Alternating Load (KN)	Mean Load (KN)	No. of Cycles N
Adhesive Bonded Joint	1	0.5	4.7 (80)	2.3	1.2	3.5	1534
	2	0.5	4.1 (70)	2.0	1.05	3.05	6037
	3	0.5	3.5 (60)	1.7	0.9	2.6	12198
	4	0.5	2.9 (50)	1.4	0.75	2.15	19645
	5	0.5	2.3 (40)	1.1	0.6	1.7	24553
Weld	1	0.5	10 (80)	5	2.5	7.5	1314

Bonded Joint	2	0.5	8.8 (70)	4.4	2.2	6.6	4456
	3	0.5	7.5 (60)	3.7	1.8	5.6	8789
	4	0.5	6.3 (50)	3.1	1.5	4.7	14367
	5	0.5	5.0 (40)	2.5	1.2	3.7	19000
	6	0.5	3.7 (30)	1.8	.95	2.7	22367

In general, the fatigue lives of both weld-bond and adhesive bond increase with reduction in maximum tensile-shear load applied during fatigue test. Weld bonds offer longer fatigue life than adhesive-bond under identical loading condition. Fatigue strength of weld bonds was found almost two times greater than of adhesive bonds in range of load studied in this work. This improvement is primarily due to the fact that application of adhesive in weld bond reduces stress concentration which in turn increases the ultimate shear tensile load carrying capacity. The adhesive provides an extra strength to the joint and protects the spot-weld nugget from minor eccentricities during fatigue testing. Observation of fracture surface of the weld-bond sample and comparison with adhesive-bonded joints, showed that an unbonded area exists around the weld nugget, which is formed primarily due to two reasons: a) the damage of the adhesive layer by heat generated during spot welding, and b) the evolution of gases generated by the thermal decomposition of the adhesive around the nugget. Both these factors in turn reduce the bonded area of the joints (Dwivedi et al., 2010). Chang et al. (2001) also concluded that under applied loads, the stresses in weld-bonded joints are low and uniform, so that weld-bonded joints have better mechanical properties and fatigue performance than spot weld. The spot weld in the weld-bonds can provide higher tear strength than adhesive-bonded joint.

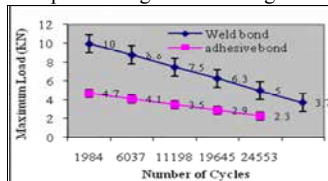


Figure 7: Fatigue test results of adhesive bond and weld-bond

3.4 Fatigue Fracture Surfaces

The photographs of fatigue fracture surface of adhesive bond and weld bond are shown in Fig. 8 (a, b). The fatigue fracture surfaces of adhesive bond shows failure of both a) adhesive layer and b) metal surface-adhesive interface. However, area on fracture surface corresponding to adhesive failure is more than that of metal surface-adhesive interface (Fig. 8a). The fatigue fracture surfaces of weld-bond show failure from three distinct ways: a) failure of adhesive layer, b) failure of metal surface-adhesive interface and c) failure weld nugget zone. Area on fracture surface corresponding to adhesive failure is significantly greater than that of spot weld zone and metal surface-adhesive interface (Fig. 8a). The shining fracture surface in weld nugget zone of the weld bond suggests the metallic failure due to overloading as shown in Fig. 8 (b). Higher fatigue strength of weld bond than adhesive bonds can be attributed to the metallic failure of the weld bonds from weld nugget zone. Closer look of fatigue fracture surfaces of weld bond using scanning electron microscopy showed fine shallow elongated dimples (like parabolas) indicating failure under tensile shear loading (Fig. 9 a, b). The fracture surface also exhibited long deep secondary cracks at the centre besides few shallow fine cracks near the edges as shown in Fig. 9 (c, d).

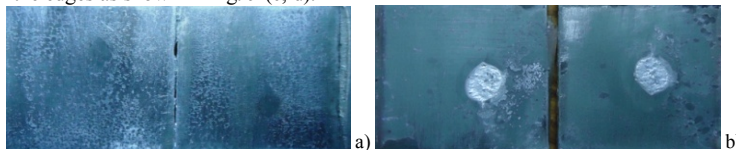


Figure 8: Photographs of fatigue fracture surface of (a) adhesive bond and (b) weld bond

Human, Robots and Digital Manufacturing

INDICATORS FOR MANAGING HUMAN CENTRED MANUFACTURING

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ABSTRACT

Establishing indicators for managing human factors (HF) aspects in the design of production systems remains a challenge. We address the problem in two dimensions – firstly, what aspects of HF are to be considered, and secondly, where in the development process HF is to be measured. In these dimensions a large number of HF metrics are possible in the perceptual, cognitive, physical and psychosocial domains of HF. The relevance of these measures to injury, productivity, quality and organizational strategy continue to be poorly understood. From this perspective we make propositions on the need for: 1) strategic HF metrics selection, 2) metrics application throughout the development process, 3) predictive ‘virtual’ HF metrics approaches, 4) metrics based design guidelines, 5) connecting metrics with design choices and strategies, 6) integrating HF metrics within existing approaches, 7) continuous improvement of the metrics system, and 8) the need to evaluate metrics system quality.

Keywords: Indicators, ergonomics, evaluation.

1 INTRODUCTION

Operational excellence in manufacturing hinges on an optimal fit between the technical system design and the capabilities of the human operators of the system. Lack of attention to Human Factors (HF) has contributed to poor productivity, poor quality, compromised implementations of new technologies or processes, and to fatigue and injuries among operators. Estimates of the cost of work-related injuries are on par with the costs of all cancers combined (Leigh 2011), with musculoskeletal disorders (MSDs) posing the vast majority of incidents. Productivity and quality losses are usually many more times the direct costs related to injury – particularly if presenteeism losses are included (Rose *et al.* in press). If these losses, caused by flaws in the design of the production system, are to be controlled then it becomes necessary to establish indicators which can support decision making among design teams and managers responsible for the development and management of operations. This view hinges on the idea that ‘If you don’t measure it, you can’t manage it’.

This discussion paper contributes towards a framework to help facilitate the development of indicators to support the design and management of more ‘Human Centered’ Production Systems (HCPS) capable of providing sustainably high performance. Towards this aim, we draw on Melnyk *et al.* (2004) three level conceptualization of metrics: the individual measures or metrics themselves; metric sets which are used to guide and evaluate an individual’s and team’s work; and metric systems which refers to the entire approach to metrics in the organisation. Furthermore, as Melnyk *et al.*

(2004) point out, the metric system should help connect and guide operational activities to the strategic objectives of the firm. In both Engineering and HF disciplines, there has been little discussion of appropriate metrics systems for designing and managing HCPS. In this paper we limit our focus to the front line employees in production, and exclude the also important discussion of the working conditions and performances of other employees in the organization.

2 DIMENSIONS OF HF METRIC SYSTEMS

In this section, we adapt Melnyk *et al.* (2004) 'focus' (e.g. financial or operational) and 'tense' (e.g. predictive or outcome) dimensions of metrics to be the 'HF aspect of interest' and the 'Stage of Development' dimensions, respectively, which frame the selection and application of HF metrics in production organisations.

2.1 Dimension 1: HF Aspect of Interest

The span of HF is diverse and covers all aspects of human-system interactions. Drawing on classical machine-human interaction theory, one can classify four main components (or sub-dimensions) of the operator-manufacturing system interaction as being 1) perceptual, 2) cognitive, 3) physical, and 4) psychosocial – the last of which we include as a special case of cognitive aspects relating to the individuals experience of work and includes constructs related to 'stress' and 'support' at work (Grosse *et al.* submitted). In each of these components a broad range of measures and indicators are possible to describe and interpret the human interaction with the environment. Perceptual aspects of the human-environment interaction reflect how someone senses their surroundings, and can be quantified in terms of the 'signal strength'. For example, Lux can describe the ambient light levels, decibels measure the magnitude of sound exposure, while an olfactometer can establish the odour levels in the air. Perceptual factors influence performance since they determine what the individual understands about the work system's status. For example, poor light levels could negatively affect a worker's ability to detect quality defects whereas sound or vibration exposures could cause a significant distraction that reduces a person's ability to focus and mask possibly important performance cues that would indicate a task was correctly completed.

Cognitive demands of work tasks include mental workload and process complexity, as well as aspects like learning and forgetting. Classifying the level of task complexity, for example, allows determinations to be made about speed of work, the tendency for errors while under time pressure, and the average rate of learning for new operators in the system. Relevant metrics for cognitive demands could include short term memory system demands, long term memory system demands, conceptual or visuospatial manipulations demands, among other aspects. If any of these systems are overloaded, for example due to excessive line speeds causing a rushed pace or due perhaps to product complexity, then errors and quality deficits can be expected outcomes. The psychosocial conditions at work, are the product of both technical decisions like layout and production flow, which affects an operator's ability to communicate, as well as the human resource management approach such as job rotation or teamwork which also affects the interaction of operators in the system (Neumann *et al.* 2006). These factors are related to 'softer' elements of immediate concern to operations managers such as 'motivation', 'turnover', or 'job satisfaction' and have also been linked to a wide range of health outcomes for operators including MSDs (Moon and Sauter 1996).

Physical HF measures, the fourth component of HF, are arguably the most studied variables in occupational ergonomics. Physical loading information can be obtained at sub-cellular (e.g. ion exchange), cellular (e.g. muscle cell), tissue (e.g. muscle or tendon), or body-part (e.g. shoulder) level for all parts of the musculoskeletal system. Alternatively, loading information can be obtained at a more macro task-based level (e.g. torque reaction in nut running). Furthermore these exposure levels may be considered in terms of their instantaneous levels, their rates or patterns of change, or for their accumulated levels as a dose over a given time period – all of which may be associated with fatigue and subsequent performance decrements, or if the exposure is high, with increased levels of discomfort and MSDs. This is based on the underlying principle that mechanical loads exceeding the individual's capacity levels can cause tissue failure with consequent performance and health effects (National Research Council 2001). With hundreds of muscles in the body and many associated tissues supporting them, the potential number of descriptive metrics in this dimension is very large.

The brief summary above suggests that there are an enormous number of indicator metrics which might conceivably be applied in a production environment and which are associated with both performance and employee well being. The challenge for developing metrics to support HCPS is to identify those aspects that are most relevant to support design and management decision making in a timely and unambiguous way. This, we suggest, is a non-trivial issue which itself warrants research: How can a company identify a manageable HF metrics indicator set to secure operational excellence in production?

2.2 Dimension 2: Stage of the Development Process

For this metrics dimension we draw on a model of the development process, shown in figure 1, which has been adapted from previous studies and has been found generally valid in field research (Neumann *et al.* 2002; Neumann *et al.* 2006). The model groups the sequence of decisions and processes within the development process into strategic, product design, production system design, and operations; with the outcomes of the system being dependant on the operator. Senior management strategies guide the choices that are made in product design. At this stage HF aspects in production are already being determined: forces required in the assembly, part weights, product complexity, task precision, and reaches required for assembly are all being influenced by the design of the product (e.g. Neumann and Wells 2007). These HF considerations have implications for product quality, operator fatigue, and injury risk.

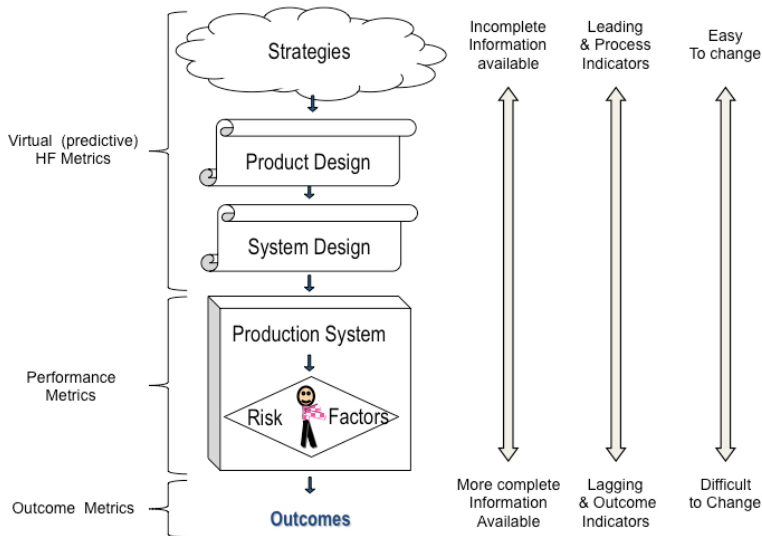


Figure 1: Model of the development system with reference to HF metrics issues

HF are further influenced in the design of the production system itself. Production system design choices, such as the flow approach, the material packaging and supply strategies, the conveyance system, the automation level, the workstation layout, and tool selection act to determine both the physical and psychosocial experience of the system operators (Neumann *et al.* 2002; Neumann *et al.* 2006). Finally, the management strategies applied in running the production system will also determine the pattern of work tasks for operators. Work scheduling, job rotation, and division of tasks will influence both the psychological and physical work pattern of the operator.

Using this model, we expand Melnyk *et al.* (2004) view of 'process' and 'outcome' indicators to include the possibility of a long chain of leading and lagging indicators which ultimately result in both human outcomes, such as increased competency, fatigue or injury; as well as system outcomes such

as, quality levels, production volumes, and delivery precision. Both human outcomes (e.g. skill or injury) and system outcomes combine to provide the overall financial performance of the system. In this model as well we stretch Melnyk *et al.* (2004) notion of tense to include ‘virtual’ metrics indicators, which are predicting operational ‘performance’ metrics where the most complete HF information is available, and which in turn affects the outcome metrics which extend outside of the production system itself.

3 IMPLICATIONS FOR ESTABLISHING AN HF METRICS SYSTEM

In this section we reflect on the implications of the two dimensions of HF metrics as discussed above. We attempt to frame these insights into ‘propositions’ which can form the basis of future research and development work on this topic. We wish to emphasise that the aim of the metrics system for which the authors are striving, is not only to reduce injuries, but to secure sustainable high performance in production in ways that support the overall company strategy.

HF of INTEREST – Given the wide range of possible HF indicators, it is necessary to select some sub-set of indicators that might reasonably be used in the development process. This selection will depend on the nature of the work being planned; electronics assembly will have a different set of relevant HF from airplane assembly for example. One important issue, often misunderstood due to traditional relegation of HF aspects to health and safety concerns, is the linkage between HF and strategic goals like quality, productivity, and flexibility (Grosse *et al.* submitted). HF risk factors for quality, for example, may include most of the risk factors for injury, but will also include aspects that pose no particular hazard to health per se – such as poor perceptual characteristics. *Proposition 1: HF metrics must be carefully selected to be the most relevant to the particular operations in terms of injury risk, quality, and other strategic goals for the system.*

EARLIEST TIME POINT – It is a fundamental characteristic of design that the costs for making change in a design, in this case to improve the fit between the technical and human system elements, increases rapidly during the development process. These costs become maximal in the case of retrofitting an existing design in running production. Beyond just cost there are an increasing number of solution constraints as the design develops. If a better solution from an HF perspective is identified later in design it is more likely to be in conflict with design options chosen earlier in the process. Any team not attending to HF in their stage of development will likely cause problems for teams further down the development chain. There is therefore a need to consider HF aspects early and throughout the development process. *Proposition 2: The metric system should allow the identification and evaluation of potential HF issues at the earliest possible stage of development where the costs of change are lowest and solution constraints are minimal.*

PREDICTIVE TOOLS – Proposition 2 creates a challenge for predictive tools. In early design stages there is relatively little information about physical, cognitive and perceptual demands available. As the product and production system design develops, however, increasingly precise information becomes available until a full data set becomes, in principle, available in real production when, ironically, there is the least latitude to make improvements. The tools used to establish metrics in the design process will, of necessity, be predictive or ‘virtual’ in nature. ‘Virtual’ HF tools can provide measures and insights into the HF issues in a design before the design exists and there is a ‘real’ operator at risk to observe. While digital human models are perhaps the most widely studied form of VHF, we apply the term to a broad range of approaches which attempt to predict demands at the conceptual stages of design. These include checklists, virtual-reality, mixed-reality, and system simulations such as discrete event simulations (Perez and Neumann accepted). Given that most ‘HF’ tools have been developed for observation of existing systems this creates a challenge – and a research opportunity. *Proposition 3: Predictive tools are required to provide metrics at early design stages and, based on current development, these tools may need to be customised for the particular production context.*

DESIGN GUIDELINES vs METRICS – To bridge the gap between designers and operators, several authors have suggested the need for HF design guidelines or standards (e.g. Campbell 1996). Indeed, numerous HF standards exist, but it has been argued that engineers and designers either do not have access to the standards, do not know how to interpret the information, or have difficulty applying the information (Wulff *et al.* 1999). Under these circumstances the criteria is not applied. While

some have suggested a guideline be supported by an HF professional, this might not be realistic for many companies. Instead we suggest that guidelines could be reinforced if framed within the context of a metric which could be used to hold the designer accountable for the extent to which they are meeting the HF specifications. *Proposition 4: Design guidelines should be applied in the form of a metric by which guideline compliance can be quantified and tracked.*

PERSPECTIVE CLASH – One challenge relating to the creation of design stage metrics and tools relates to the disconnect between the system design perspective of the engineering team and the task perspective of the system operators. Grosse *et al.* (submitted) have illustrated the perspective clash for the case of order picking systems: While engineers are focused on system elements like layout, storage assignments, routing, and work organization, the operator's HF related demands are linked to their tasks including: set-up, travel, search and pick. The technical choices of the engineering team do not have a one-to-one mapping onto a given HF aspect. For example the neck posture (adopted to assist in vision of a given product code) of an employee engaged in 'search' may depend on a combination of the racking used, the location of the code-slip, the size of the font, the lighting level, and the transport device of the operator (e.g. lift truck vs. cart). Similarly a given choice in racking may affect perceptual and physical aspects for several different tasks. *Proposition 5: Metrics and underlying design criteria need to be designed in ways that span the perspective clash between the technical design aspects and the HF relevant to performance.*

CONSIDER ADOPTION ISSUES – While one might think that there is a need for a specific set of tools to generate metrics throughout design, this might not be the most cost effective approach. Not only does this raise issues of cost and time to use the new tools, it also poses a problem of acceptance by engineers unfamiliar with these approaches. Instead, companies could consider adapting existing tools and approaches to include HF metrics alongside the traditional indicators. For example, the common 'Failure Mode Effects Analysis' (FMEA) approach can be adjusted to include specific HF aspects of relevance to the production context. These tools can lead to a more rapid uptake of HF in the design process because engineers are already familiar with them, and may also make it more difficult to ignore HF aspects that are inconvenient. We note here also that including the perspectives of the design team (the 'user' of any metric generating tool), in a participatory way, will likely help produce improved methods and acceptance of the resulting HF metrics approach. *Proposition 6: Adapting existing metrics approaches (tools) to include HF may be more effective than trying to develop and adopt separate methods.*

DYNAMIC METRICS SYSTEMS – Metrics systems need to be developed on an ongoing basis. One reason is that production strategies keep evolving, which implies that the way production operators work will also change and that new demands or different HF metrics will need to be applied to ensure the system will function as required. A second reason for the development is that the predictive 'virtual' tools used in earlier design stages are, of necessity, using incomplete information about the system. It is necessary therefore to have some means of ensuring that the 'predicted' HF metrics are accurately capturing the eventual actual demands in running production. *Proposition 7: The metrics system needs to have a mechanism to periodically check if the right HF are being captured, and to adapt the metrics prediction approach to better match the actual HF demands experienced in real production.*

METRICS SYSTEM OVERVIEW – How is a manager to know if they have a good approach to managing HF in their company? Compared to other issues, such as environmental aspects, there is no standard management system and no 'audit' type approach that would help the manager understand where improvement opportunities exist. In short, there is no approach to understanding the quality of a metrics system either with regards to other companies (benchmarking) or with regard to some idealised situation (auditing). This issue poses a challenge for both researchers and companies. *Proposition 8: There is a need for an approach to evaluating the completeness of a company's approach to managing and capitalising on HF aspects in their production system; an approach to scoring a metrics system's quality.*

4 DISCUSSION & CONCLUSIONS

This paper has attempted to understand the challenge of establishing metrics for HCPS design in the face of a very large number of possible HF metrics, which are influenced over a series of design stages which are themselves not understood in terms of the HF they affect. From this exercise 8 propositions have emerged regarding: 1) selection of appropriate HF metrics, 2) establishing metrics throughout the development process, 3) customising predictive 'virtual' HF metrics approaches, 4) implementing design guidelines in the form of metrics, 5) linking metrics to specific design choices and strategies, 6) adapting existing approaches rather than inventing new, separate metrics tools, 7) having an approach to improve and update the metrics system over time, and 8) the need for an approach to evaluating the overall quality of the metrics system. HF in manufacturing metrics systems has not been widely examined. While this paper contributes to this goal, it raises almost as many questions as it answers. There is considerable research required to understand what an optimal HF metrics system might be and how that system can help companies achieve sustainable competitive advantage in the pursuit of its strategic goals.

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HUMAN-AUTOMATION COLLABORATION IN MANUFACTURING: IDENTIFYING KEY IMPLEMENTATION FACTORS

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ABSTRACT

Human-automation collaboration refers to the concept of human operators and intelligent automation working together interactively within the same workspace without conventional physical separation. This concept has commanded significant attention in manufacturing because of the potential applications, such as the installation of large sub-assemblies. However, the key human factors relevant to human-automation collaboration have not yet been fully investigated. To maximise effective implementation and reduce development costs for future projects these factors need to be examined. In this paper, a collection of human factors likely to influence human-automation collaboration are identified from current literature. To test the validity of these and explore further factors associated with implementation success, different types of production processes in terms of stage of maturity are being explored via industrial case studies from the project's stakeholders. Data was collected through a series of semi-structured interviews with shop floor operators, engineers, system designers and management personnel.

Keywords: human-automation collaboration, human-robot interaction, industrial ergonomics, human factors.

1 INTRODUCTION

In a traditional manufacturing environment, industrial robots work in isolation from human operators (Wilcox, Nikolaidis and Shah 2012). However, this segregation does not assist the need to increase production and reduce costs while maintaining a high quality product output in manufacturing (Buckingham *et al.* 2007). As considerable benefits can be gained when shop floor operators collaborate in real time with intelligent automation this has led to significant attention to the potential for human-automation collaboration (HAC) in certain manufacturing applications, such as the installation of large sub-assemblies (Walton, Webb and Poad 2011). In light of recent advances in technology which will enable HAC potential, health and safety regulations are also being advanced and updated to reflect that in some circumstances it is safe and viable for humans to work more closely to industrial robots (International Standards Organisation 10218:2-2011).

Despite recent developments, we do not yet fully understand how human operators will behave in these collaborative environments because it has still not yet possible to implement industrial HAC under current health and safety legislation. It has long been realised that neglecting human factors issues can be detrimental to the successful introduction of advanced automated systems (Frischia 1990). Parasuraman and Wickens (2008) claim that despite advances in automation, the vital link for successful operation of intelligent automation is still human presence. However, as the development of HAC systems in manufacturing is still at an emergent stage there remains a paucity of literature identifying the key human factors that are likely to influence successful adoption. There has simply not yet been real examples of industrial HAC implementation in which to research antecedent factors and impacts.

The aim of the investigation described in this paper is to address the current gap in knowledge by identifying and evaluating the human factors of most influence in relation to the introduction of HAC in manufacturing. The following sections describe how a theoretical framework of factors was derived

from literature that might be comparable to the HAC context and this was examined for validation purposes in the collection of data from a case study of real operational automation implementation.

2 HUMAN FACTORS INFLUENCING HAC: THEORETICAL FRAMEWORK

This section describes the process employed to identify the human factors likely to influence the adoption of HAC and the set of key factors or themes that emerged in this process.

2.1 Classification of Selected Human Factors

As this study is aiming to capture human factors at different levels across the organisation, the factors identified were classified into two sub-categories based on their relevance to the human operator or the wider organisation:

- (i) Factors at the individual level: influencing the human operator
- (ii) Factors at the organisational level: influencing the organisation

2.2 Human Factors at the Individual Level

Trust in robots/automation: Trust in human-automation collaboration has been cited as an important factor because it can influence the success of the interaction (Billings *et al.* 2012). Hancock *et al.* (2011) suggest that robot-related factors such, performance can have the highest impact on trust.

Mental Workload: For HAC collaboration to succeed, both agents need to interact in an effective manner. According to authors, automated systems have reduced physical demand on humans but have introduced additional cognitive demands which increase workload, hence hindering the effectiveness of the collaboration (Megaw 2005).

Loss of Situation Awareness (SA): Automating a manual process can potentially leave human operator out-of-the-loop, passively monitoring the system and intervening only during a system failure. This condition can lead to loss of SA resulting costs to human performance (Parasuraman, Sheridan and Wickens 2000).

Introduction of Varying Levels of Automation: Introduction of automation is based on the notion that it will assist human operators and facilitate optimal operation (Balfe *et al.* 2012). However, full automation can change the role of human operators to passive monitoring. This has been found to cause skill degradation, loss of SA and complacency (Parasuraman, Sheridan and Wickens 2000).

Stress, Anxiety and Safety due to HAC: Collaboration in real time between humans and robots is bound to have the two agents in close proximity with evident the possibility of collision. However, it is not yet understood how the interaction will influence acceptance by human users (Zecca *et al.* 2007). More recently, Aria *et al.* (2010), in a novel cell production assembly experiment, found that robot size and robot speed had increased mental strain.

Effects Automation Reliability: Automation reliability can influence successful co-operation between humans and automation. Parasuraman *et al.* (1993) in their study found automation reliability can potentially introduce automation-induced complacency effects. Similarly, Rovira, McGarry and Parasuraman (2007) found that higher automation reliability increased complacency which can have a significant cost during automation failure.

Perceived Attentional Control (PAC): Automating a process will require the operator to monitor the supervise the state of the system. In such applications, operators will be required to divide attention across a number of processes in order to gain information about the system while looking for critical events (Tallner and Wickens 2003). Previous research has found that poorer allocation of attention, can significantly detriment human performance particularly during a system failure (Chen 2011). This can pose an obstacle towards the success of a HAC system.

Attitudes towards Robots/Automation: Recent evidence suggests that people tend to perceive assistive robots more as companions and social actors rather than tools and this can potentially enhance acceptance positively (Torta *et al.* 2012). Furthermore, Nomura *et al.* (2006a) found that negative attitude towards robots can barrier interaction with robots in daily life. Although these occasions mostly relate to social robots, it would be important to investigate whether negative attitudes can barrier interaction in a manufacturing environment

2.3 Human Factors at the Organisational Level

Communication to the Workforce: Communication of quality information during an organisational change can alleviate the associated uncertainty which has been linked with negative effect on psychological well-being (Allen, *et al.* 2007). Hence, lack of communication can induce a psychological state of doubt and endanger acceptance of the system.

Training and Development of the Workforce: A key theme appearing on the literature is the training and development of the workforce (Waldeck 2007). It has been declared that, workforce development is an important feature during AMT implementation that can promote organisational performance.

Formation of a Multidisciplinary Team: Investigation of the factors that enabled the successful implementation of AMT on the shopfloor indicated that the establishment of multidisciplinary teams from various departments can have a major positive impact (Bidanda, *et al.* 2005).

Worker Involvement in the Implementation: Worker involvement has been linked with successful implementation of a technological system (Sohal 1999). Therefore, the degree of employee participation can be a potential enabler for successful adoption of HAC.

Identification of a Process Champion: The presence of a technology champion during the implementation phase can be a significant factor. This can be a knowledgeable person, who understands the technology and its benefits so that it can motivate people around them. Also, it has to appear credible to the workers in order to reduce resistance (Chung 1996).

Organisational Flexibility and Top Management Commitment: According to a number of studies, top management commitment can be a key factor. The management team needs to be involved throughout the process and not simply with technical aspects of the project. Also, Zammuto and O'Connor (1992) support that an organic culture is the key to exploiting the benefits of advanced automated technologies.

Trade Unions: The degree of a firm's unionisation level has been reported to influence the introduction of automated systems. Certain studies have indicated that unions do not always resist the introduction of technology (Small and Yasin 2000). Some others have found that union involvement from the beginning can be a way to handle such a sensitive issue.

3 DEVELOPMENT OF METHODOLOGY

This section describes the methodology used to (i) investigate the validity of the set of human factors identified in the theoretical framework and (ii) capture additional human factors as they appear from the collected data.

3.1 Case Study Selection

To identify and evaluate the key factors that are either enablers or barriers in relation to HAC in manufacturing, a range of appropriate production processes in various manufacturing settings were considered as case studies. Two types of processes in terms of stage of maturity will be explored: (i) a relatively mature, post-automation process and (ii) an example of in-progress automation implementation. To date, the second example of in-progress automation has been investigated to explore the factors that are affecting the process change and its adoption.

3.2 Data Collection and Analysis

The lack of previous industrial HAC research or existing guiding framework meant that for this study an exploratory approach was appropriate. Instead, the list of human factors themes that had been identified in the literature was used as an *a priori* guiding framework within a semi-structured interview approach to gather individual experiences and accounts of the transition from a manual to an automated process. Interview participants were personnel who were involved in the implementation such as: shopfloor operators, engineers, system designers, and management personnel. Interviews were fully transcribed and analysed using the 'Template Analysis' in accordance with guidelines provided by Crabtree and Miller (1999), and King *et al.* (2002). The process involves the development of a coding template representing the major themes identified in a hierarchical form so that top level codes represent broad themes while lower level codes represent composite sub-themes. The template structure was revised iteratively to ensure it reflected the data in the most suitable manner.

3.3 RESULTS AND DISCUSSION

Through the data analysis, several enablers and barriers have emerged. Due to space limitations the most important are outlined below:

Enablers

Worker involvement in implementation: Shop floor employees can input their knowledge and experience to successfully implement the new automation. At the same time, through their involvement shop floor employees gained ownership of the new system which enhanced acceptance.

Communication to the workforce: Results indicated that early communication regarding the benefits of the new automated process to the workforce is an important enabler. Through communication employees were kept informed and reduced resistance when the automation arrived on-site.

Top management commitment and support: Commitment of senior management was found important to ensure the project can progress and be implemented. At the same time, it was pointed to be vital for keeping personnel at all levels focussed on the aims of the project and to raise morale.

Training of the workforce: During the early implementation stages, provision of offsite training to a number of end-users was found to be an important enabler. It allowed end-users to gain confidence and ownership of the new system. Also, the end-users trained initially were able to translate their knowledge and experience to the rest of their colleagues on the manual cell. This reduced negativity regarding the system, prepared the rest of the employees and enhanced acceptance.

Organisational flexibility through worker empowerment: Empowering operators with additional control over the new system was found to be an enabler. Results pointed that this gave operators a more active role rather than passively monitoring the automation.

Barriers

Communication interface between union-local management: Results suggested that effective communication with local union leaders regarding the rationale of introducing the automation and the impact on employees is important.

Awareness of manual process complexity by system integrator: It was pointed that system integrator needs to have a comprehensive understanding of the variability of the manual process to be automated. Insufficient understanding can cause delays to the development of a robust and process capable system.

Capturing manual process variability: Lack of capturing the source of variation of complex manual processes can pose significant challenges. As highlighted above, capturing the manual process variability can be fed to the system integrator to support the provision of a process capable system.

Resources required for the development of the automation: Resource allocation to the development of the automation is likely to have a negative impact on the production rates. This was found to create confusion between the production and the development teams. Moreover, it was identified that the confusion can have a negative effect on shop floor employees assigned to support the automation.

4 CONCLUSION AND FUTURE WORK

This paper has presented research work in progress that is being conducted to advance the potential for HAC to be developed and implemented. It has presented the key human factors that were identified through a literature review as most relevant to successful implementation of industrial automation as well as the methodology developed to collect and analyse data to test the relevance and validity of these factors for industrial HAC contexts. It is evident that a single case study will not provide robust and generalisable findings. Hence, to identify factors that are barriers or enablers to the implementation of HAC, a survey has been constructed based on the findings of the case study. The survey has been administered to appropriate subject matter experts (SME) who were involved in the automation of manual processes. Ten SMEs have been approached and data is currently being collected. Future work involves the administration of surveys to different sized and structured organisations to observe any variability of the factors and identify where any antecedents or impacts are specific. Also, Different manufacturing sectors will also be covered in order to identify context-specific factors.

By capturing further data this research will be able to produce a valid framework of general organisational level factors that need to be considered for the implementation of HAC systems into manufacturing processes. At the same time this cross-organisational, multi-sector approach will be able identify more context-specific antecedents and likely outcomes.

Apart from investigating how organisations implement intelligent automated systems, it is equally important to investigate the key factors that will enable effective interaction between operators and robotic assistants. One of the most important aspects for successful interaction identified in the literature is the level of trust of the human operator to the robotic teammate (Yagoda and Gillan, 2012). Facilitating appropriate levels of trust can determine acceptance of a system and reduce negative performance outcomes (Yagoda 2013). However, very little research has focused on the development of a trust measurement inventory for industrial human-robot interaction (HRI). For this purpose an exploratory experimental study is in progress to develop a psychometric scale to measure trust in industrial HRI.

By collating the organisational level and individual level factors, will provide a highly useful design aid for implementing industrial human-robot collaboration.

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POSITION CONTROL OF AN INDUSTRIAL ROBOT USING AN OPTICAL MEASUREMENT SYSTEM FOR MACHINING PURPOSES

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ABSTRACT

A series of mechanical properties and disturbances limit the accuracy achievable in robotic applications. External control of the end effector position is commonly known as being an appropriate mean to increase accuracy. This paper presents an approach for position control of industrial robots using the pass-through between an industrial CNC and servomotors. A CNC-controlled robot is used together with an external optical measurement system to close the feedback loop of robot end effector and robot controller in order to improve robot accuracy. For short cycle times and implementation reasons a PLC is used for signal processing and control implementation. The relevance of the approach is outlined in experiments. The robot behaviour in free space motion and in machining application is analysed with the optical measurement system and a CMM.

Keywords: Robot position control, robot end effector tracking, robot machining.

1 INTRODUCTION

Limited stiffness and limited position accuracy reduce the impact of industrial robots in machining applications. In order to achieve better surface quality different approaches have been presented. Kinematic calibration (Dietz *et al.* 2012) as well as deflection compensation have been investigated in the past (Abele *et al.* 2011). However, the consideration of kinematic effects and dynamic effects could further improve the performance. Dynamic effects are in particular such as backlash, compliance and friction as well as temperature effects and disturbances from the environment. Schmitt, Norman and Mosqueira use an iGPS system to compensate for those effects in an handling operation (Schmitt *et al.* 2010, Norman *et al.* 2012, Mosqueira *et al.* 2012). Schuetze and Ziegler use photogrammetric measurement systems in order to improve positioning accuracy (Schuetze *et al.* 2009, Ziegler *et al.* 2011). Another method for end effector tracking is proposed by Drust *et al.* 2011. This approach measures the variation of projections to control the robot. Wang analyses the end effector tracking of robots with iGPS and lasertracker and compares them (Wang *et al.* 2011). The presented results are promising. However, they do not show the relevance of the approach in high-frequency applications like machining. In machining process disturbances influence the positioning of the robot and require a fast and dynamic compensation. This topic will be addressed within this paper.

Within the European FP7-project COMET different compensation approaches are addressed in order to reduce surface tolerances to 50 μm (COMET 2012). Kinematic and dynamic robot models are used to predict deviations and to compensate for them. Further online compensation is used to compensate and push precision beyond 100 μm .

This paper is organised as follows. Section 1 introduces the topic. Section 2 describes the experimental setup and the implementation of interfaces and controllers and is followed by Section 3 explaining the experimental validation of the performance with free space robot movement and robot machining experiments. Finally conclusions are reached affirming improvement for the robot's positioning accuracy with the implemented control.

2 SETUP AND IMPLEMENTATION

In order to show the real potential of end effector control a robotic machining cell is set up and all required components are integrated. A KR125 industrial robot from KUKA together with a K600 measurement system from Nikon Metrology and a Chopper 3300 spindle from Jaeger are combined on a 14 t machine bed (see Figure 1). The K600 measurement system fulfills all key requirements needed for a robotic machining process: Short cycle time, robust measurements, precision. The sensing of a series of LEDs with three cameras in an appropriate workspace allows to measure several frames with an accuracy of $\pm 90 \mu\text{m}$ in a cycle time up to 1 kHz. The possibility to attach redundant LEDs is essential in order to provide a constant measurement signal while shadowing LEDs by robot movements or disturbances from the machining process such as chips or lubrication.



Figure 1: Robotic machining cell with K600 measurement system, Chopper 3300 spindle and KR125 robot.

In order to optimize path generation and to provide proper interfaces the KR125 hardware is driven by TwinCAT CNC control from Beckhoff. The extended look-ahead as well as the adjustable trajectory planning of the CNC kernel allow to optimize the robot path for the machining requirements. The trajectory planning task is interfaced to the PLC where signal processing, computation of corrections and signal routing is performed. The corrected signals are then fed to the servo-drives (see Figure 2).

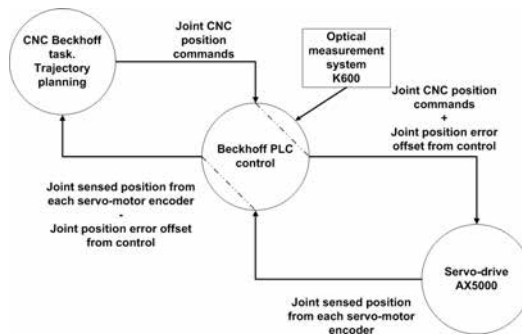


Figure 2: Combination of CNC-kernel, PLC, K600 and drives to a closed loop control system

Via a TCP connection the PLC receives the measurements of the K600 measurement system containing the 6D pose of the robot's end effector. Figure 3 shows the cycle time analysis of the K600 communication. A state machine is used to organize the communication. In state 2 the TCP stack is read lasting 1.7 ms. The PLC task is set to a cycle time of 10 kHz in order to minimize calculation time between stack readings. The sum of stack reading and communication routing results in a maximal polling frequency of 500 Hz. Considering the bandwidth of industrial robots of < 30 Hz (Schneider *et al.* 2013) 500 Hz is considered to be sufficient for end effector control of industrial robots.

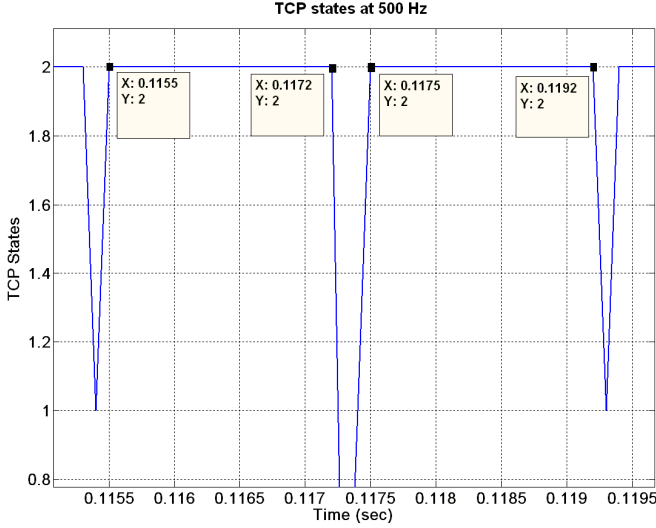


Figure 3: TCP communication between PLC and K600: Stack reading lasts 1.7 ms

As the transformation between joint and Cartesian space is performed within the CNC-kernel control adjustments need to be performed on joint level. As measurements are only available in Cartesian space a mapping to joint space needs to be performed. The error between Cartesian reference and measurement is transformed to joint space using the inverse Jacobian (see Equation 1).

$$\delta Q = J^{-1} \delta X \quad (1)$$

As the correction offsets are expected to be small the linearization of the Jacobian is valid and Cartesian offsets will be transformed to joint offsets until the errors are compensated for. Depending on the operational mode of the CNC kernel the Cartesian pose is not always available. In order to be independent from the operational mode, a forward kinematics implementation is used to compute the Cartesian pose. The description of Denavit-Hartenberg is used to deduce the 6D pose. The analytical expressions of forward kinematics and Jacobian are implemented in the PLC. Mathematical simplifications of the analytical terms to reduce computation time and functionalities to detect singularities are applied. A general scheme for the implemented position control is depicted in Figure 4.

6 digital PID controllers are implemented on joint level. Manual tuning of controller gains k_p , k_v and k_i (see Equation 2) with the input q and the output τ leads to the results depicted in Section 3.

$$\tau = k_p q + k_v \dot{q} + k_i \int_0^t q(\sigma) d\sigma \quad (2)$$

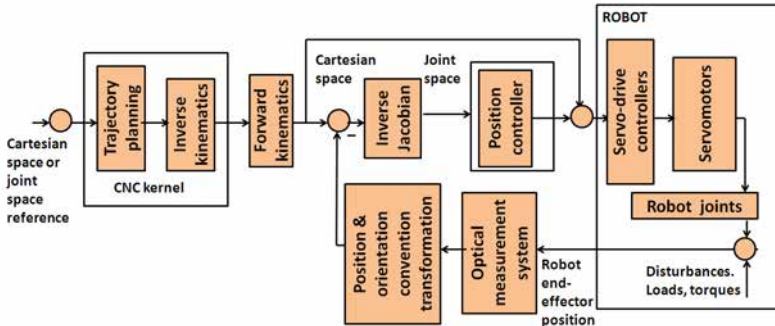


Figure 4: General scheme for the implemented position control.

3 EXPERIMENTAL VALIDATION

In order to analyse the performance and improvement of the system experiments have been conducted. First the performance of this implementation is evaluated by measuring the trajectory accuracy of a circular path as defined in the ISO 9283 standard. Finally, machining experiments are performed and measured on a Coordinate Measurement Machine (CMM) in order to depict the control performance.

3.1 Validation in Free Space Motion

ISO 9283 describes the standard for determination of robot accuracy (ISO). The movement is designed as a circular trajectory of 210 mm of radius inclined 45 degrees. The movement is performed in a designed work space close to the spindle in order to point out the relevance for the machining application. The feed rate was set to 1000 m/min as it is typically used in machining. Table 1 depicts the calculated trajectory accuracy for both the uncontrolled robot and the robot controlled by the feedback loop with the external tracking system. Figure 5 depicts the XY plane of the circular movement pointing out the improvements. A similar result can be observed in XZ and YZ planes.

Table 1 points out the trajectory accuracy calculated according to the standard. Accuracy could be increased by 33.76% by means of feedback control.

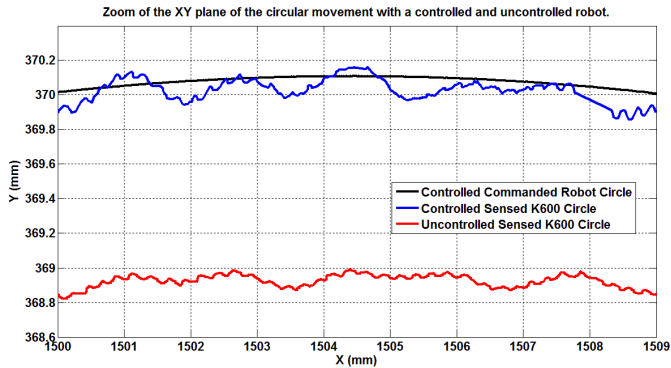


Figure 5: Comparison of circular movements with a controlled and uncontrolled robot.

Table 1: Trajectory accuracy according to ISO 9283 for the free space movement experiment.

Trajectory Accuracy (mm)	
Robot without control	1.7133 mm
Robot with control (Final PI tuning)	1.1348 mm

3.2 Validation in Machining Experiments

A circle with a diameter of 70 mm is machined in steel to show the relevance of the approach in machining operation. The circle is placed in the YZ plane of the robot. With a stepdown of 0.5 mm and a feedrate of 300 m/min an 8 mm solid-carbide tool “HPC TiSi” from HOLEX is chosen to operate in full width cut. No lubrication or cooling is used. The machining result is analysed with a "Videocheck HA400" coordinate measuring machine (CMM) from Werth. By raster scanning point clouds of the inner and the outer circle can be captured and then subsequently be compared to ideal circles. Figure 6 depicts the circles captured by the CMM and the nominal circles.

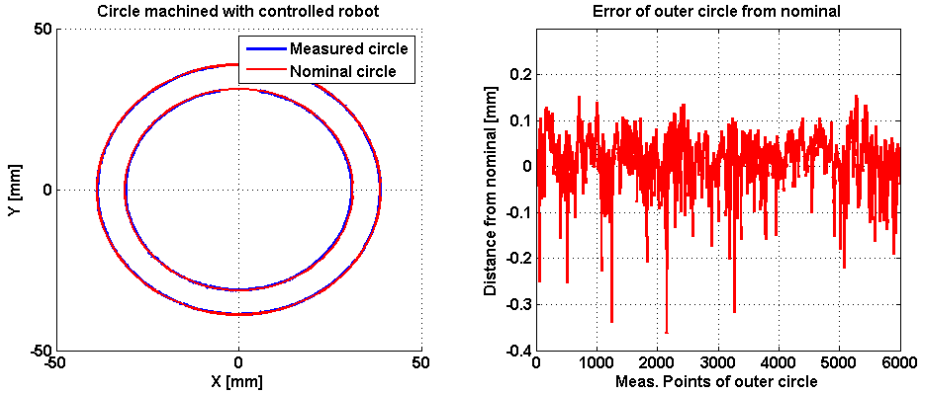


Figure 6: (Left) Contours for the machining with a controlled robot. (Right) Errors of the measured points from the nominal circle

The results are evaluated using the Mean Absolute Error (MAE) (see Equation 3).

$$MAE = \sum_{t=1}^T \frac{|X_t - X_f|}{T} \quad (3)$$

“Where X_t = observed value of data at time t , X_f = forecasted value, and T = total number of observations at time t .” (Hyndman *et al.* 2006). The comparison of the two experiments is listed in Table 2.

Table 2: Mean Absolute Error for the machining with uncontrolled and controlled robot.

	MAE Inner Circle (IC)	MAE Outer Circle (OC)	(IC + OC)/2
Robot uncontrolled	252 μm	255 μm	253 μm
Robot PI controlled	80 μm	47 μm	63 μm

As expected the result with the controlled robot is better than the result with the uncontrolled robot. The improvement for the conducted test can be quantified by 75%. It should be noted, that the improvement in machining operation is even higher than in free space motion. This can be explained by disturbances due to the machining process which deflect the robot in uncontrolled configuration whereas the deflection can be compensated when machining in controlled configuration. Further, it should be noticed that the combination of redundancy of LEDs and intelligent signal routing enables an optical measurement system to provide robust control behavior in machining environment where disturbances such as chips and dust are available.

4 CONCLUSION AND FUTURE WORKS

This paper describes a novel approach of implementation and evaluation of a position control using an external optical measurement system for machining purposes. A CNC controlled robot is interconnected with a K600 system and a closed loop control is set up. Under consideration of sample times and delays the system has been optimized for fast, robust and precise robot positioning. The performance of the approach is evaluated in free space motion as well as in machining operation in steel. Results are examined on a CMM and applicability of the approach has been proven. Improvements of 46.88% could be experimentally demonstrated.

More advanced control approaches could be considered in future works. Using models describing the dynamics of the system, model-based control systems could be set up and performance of the system could be increased.

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FREE SINGULARITY PATH PLANNING OF HYBRID PARALLEL ROBOT

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ABSTRACT

This paper presents a singularity-free path planning approach for a hybrid parallel robot. The hybrid robot is composed of two well-known parallel robots, a hexapod and a tripod, that are serially connected. In this paper a methodology is developed to avoid singularity configurations of the hybrid parallel robot. Nominal polynomial paths are used for motion of end effector, and the strokes of each actuator is calculated by using the developed inverse kinematic. A MATLAB program has been developed to generate the designed paths, and several poses have been tested in a CAD model of the hybrid parallel robot to validate the feasibility of the path planning approach.

Keywords: Parallel Robot, Path planning, Singularity.

1 INTRODUCTION

Parallel robots are close loop mechanisms which are utilized in industry for various applications, such as flight simulation, machining and pick and place operation. Compared with serial manipulators, parallel mechanisms have higher operating accuracy, although they maintain the disadvantage of exhibiting low work volume compared to serial manipulators. The hexapod manipulator is a 6-UPU parallel mechanism, which has six prismatic legs and two circular platforms, the legs are connected to the platforms with universal joints. Each of the six legs can move linearly which is driven by a linear electric motor. Therefore, this parallel mechanism has 6 degrees of freedom (6-DOF). This hexapod parallel robot is designed based on the Stewart Platform manipulator, which is one of the most well-known models in the family of parallel robots. The detailed introduction of the Stewart Platform manipulator has been investigated (Merlet, 2006). The tripod parallel manipulator is constructed on the upper platform of the hexapod robot, and the end-effector is positioned on the upper platform of the tripod manipulator. There have been various investigations of the kinematic analysis of the parallel mechanisms (Chen *et al.* 2009). This hybrid parallel robot is designed to provide a tradeoff of merits and demerits of close loop and open loop mechanisms (Haddab *et al.* 2013). By serially connecting these two parallel mechanisms together, the hybrid parallel robot gains a larger work space without losing its inherent advantages over serial robots. To plan paths for parallel manipulators, the singularity configurations of the manipulator should be avoided. Kinematic singularities are particular poses of the end-effector where parallel robots lose their inherent infinite rigidity. Two types of serial and parallel singularities have been categorized (Rost *et al.* 2011). It is widely believed that serial singularities are obtained on the boundary of workspace, while parallel singularity presents when the actuator forces on the legs cannot be supported. The path planning approach of the hybrid parallel robot is developed based on its inverse kinematic analysis. Inverse kinematic analysis gives the relationship between position of joint and end-effector poses based on the physical structure of a

robot. For each given pose of the end-effector, the inverse kinematic analysis calculates out the length of actuators on each leg of the robotic mechanism.

A criterion of singularity configurations for the Stewart Platform manipulators is presented (Dasgupta *et al.* 1998). They also developed a singularity-free path planning method based on linear interpolation and conquer algorithm. A singularity-free path planning approach considering the kinetic and potential energy of parallel mechanisms for various types of parallel robots have been introduced (Sen *et al.* 2003) using Euler-Lagrange equations to solve the singularity-free path, (Anjan *et al.* 2005) described a singularity-free path planning algorithm by grouping singularity points into various clusters. Currently, a number of researchers have investigated the issue of singularity-free path planning problems for parallel robots, especially for the Stewart platform parallel manipulators (Jazar *et al.* 2007).

1.1 Inverse kinematic

Positions of joints attached to platforms are calculated by using transformation matrix while initial positions of joints are fully defined. Figs.1 and 2 show the simulated and the physical prototype of the hybrid parallel robot that is considered in this paper.

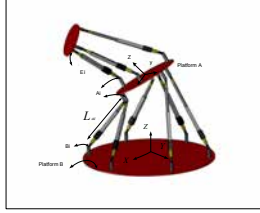


Figure 1: Hybrid parallel robot CAD model



Figure 2: Hybrid parallel robot physical model

Position vectors of the hexapod are developed by equation.1.

$$\mathbf{L}_{Hi} = \mathbf{A}_i \times \mathbf{T}_B^A - \mathbf{B}_i \quad i \in \{1 \dots 6\} \quad (1)$$

Where, $\mathbf{L}_{Hi}$ is position vector of each actuator connecting platforms B and A, $\mathbf{T}_B^A$ is transformation matrix for platform A, $\mathbf{A}_i$ is initial position of joint on platform A, and $\mathbf{B}_i$ is position of joints on platform B.

Moreover, the transformation matrix for hexapod structure was calculated based on three rotations motions and three translation motions as in equation.2 (David F, J. Alan. 1990).

$$\mathbf{T}_B^A = \mathbf{T}_{l,m,n} \times \mathbf{R}_\varphi \times \mathbf{R}_\psi \times \mathbf{R}_\theta \quad (2)$$

Where, φ , ψ , θ are defined rotational components and l, m and n are linear motions in X, Y, Z directions respectively. The transformation matrix platform E (End Effector) is related to platform B, as given in equation 3.1.

$$\mathbf{T}_B^E = \mathbf{T}_A^E \times \mathbf{T}_B^A \quad (3.1)$$

$$\mathbf{T}_A^E = \mathbf{T}_{i2} \times \mathbf{R}_{\varphi_i} \times \mathbf{R}_{\psi_i} \quad (3.2)$$

Where, $\mathbf{T}_B^E$ is transformation matrix of platform E related to B, $\mathbf{T}_A^E$ is transformation matrix of platform E related to B, and $\mathbf{T}_B^A$ is transformation matrix of platform A related to B, as defined in equation 3.2.

Therefore the length of each actuator is calculated by equation 4.

$$\mathbf{L}_{Ti} = \mathbf{E}_i \times \mathbf{T}_B^E - \mathbf{A}_i \times \mathbf{T}_B^A \quad i \in \{1 \dots 3\} \quad (4)$$

Where, $\mathbf{L}_{Ti}$ is position vector of each actuator connecting platform A and E, $\mathbf{E}_i$ is initial joint position on platform E, and $\mathbf{A}_i$ is joint positions on top of platform A.

1.2 Singularity

In general, the singularities happen while some of the vector force of actuators in particular poses and orientations of the end effector are zero. Singularities in workspace can be calculated by identifying

the force transfer matrix of the structure. A typical consequence caused by the singularities of parallel robots is the collapse of the parallel structure.

The proposed hybrid structure composes of nine actuators that connect two moving platforms and a fixed platform. Inverses kinematic analysis determines position vector of actuators that are not related to one other. Unit vector of each actuator demonstrates the direction of the force created by the actuators.

In the Cartesian space (global frame), the pose X of the end-effector is determined by the position variables ($x \ y \ z$) and orientation variables ($\alpha \ \beta \ \gamma$), as can be expressed in equation 5.

$$X = [x \ y \ z \ \alpha \ \beta \ \gamma]^T \quad (5)$$

The exerted force on top platform hexapod (platform A) is developed on equation 6.

$$F_{in}(X) = [F_1 \ F_2 \ F_3 \ F_4 \ F_5 \ F_6]^T \quad (6)$$

Where, F_{in} is the force matrix of hexapod created by actuators on platform A and F_i actuator force.

In order to calculate the vector force, unit vector of actuators are obtained as shown below:

$$s_i = \frac{L_{Hi}}{\|L_{Hi}\|} \quad i \in \{1 \dots 6\} \quad (7.a)$$

$$F = \sum_{i=1}^6 s_i F_i \quad (7.b)$$

The created momentum on the platform A due to linear forces of actuators is obtained by equation 8.

$$M = \sum_{i=1}^6 (A_i \times s_i) F_i \quad (8)$$

The results of actuators force for each motion could be defined in a matrix that is expressed in equation 9.

$$F_{out}(X) = [F \ M]^T \quad (9)$$

The relations of input and output loads of the hexapod parallel manipulator can be given by

$$F_{out}(X) = H(X) \cdot F_{in}(X) \quad (10)$$

The matrix $H(X)$ is a 6×6 force transformation matrix which indicates how the output load is related to the input forces.

The force transformation matrix of the hybrid parallel robot is obtained as:

$$H(X) = \begin{bmatrix} s_1 & s_2 & s_3 & s_4 & s_5 & s_6 \\ A_1 \times s_1 & A_2 \times s_2 & A_3 \times s_3 & A_4 \times s_4 & A_5 \times s_5 & A_6 \times s_6 \end{bmatrix} \quad (11)$$

The force transformation matrix H represents the relations between the input forces F_{in} and the output forces F_{out} . When $H(X)$ is singular, the transformation equation (2) will be degenerated and some loads (forces and/or moments) on the upper platform cannot be supported by the actuator forces. As a result, the end-effector gains some extra degrees of freedom and become uncontrollable.

Therefore, the criterion of the singularity configuration of the hexapod platform is equivalent to the singularity of the force transformation matrix. Therefore, the criterion of the singularity configuration of the hexapod parallel manipulator is given as given in equation 12.

$$\det(H(X)) = 0 \quad (12)$$

Where, $\det$ is a command defined to calculate the determinant of a matrix in MATLAB.

The boundary singularity configuration is determined by the boundary conditions of the hybrid parallel robot, the boundary conditions are determined by the length limitations of the nine actuated legs. The boundary condition of the hybrid robot can be expressed as given in equation 13.

$$L_{min} \leq L_i \leq L_{max} \quad (i = 1 \text{ to } 9) \quad (13)$$

Where, $L_{min} = 226.11 \text{ mm}$ and $L_{max} = 326.11 \text{ mm}$. Thus, the criterion of singularity configurations of the parallel robot consists of the criterions of serial and parallel singularities. The singularity-free condition of the hybrid parallel robot can be expressed as:

$$\det(H(X)) \neq 0, \text{ and } L_{min} \leq L_i \leq L_{max} \quad (i = 1 \text{ to } 9) \quad (14)$$

2 SINGULARITY-FREE PATH PLANNING APPROACH

2.1 Initial polynomial paths for end-effector

The path planning approach for the hybrid parallel robot starts with defining an initial nominal path to connect two given poses of the end-effector in workspace. Initially, a straight line is used as the

nominal path. However, when the end-effector moves along the considered path, large accelerations are present along the path especially at the start and end pose.

This problem is solved by using a polynomial path as the nominal path. As a polynomial path is smooth the acceleration of the path can be considered using high degree polynomial equations. A detailed description for generating polynomial path is introduced by Reza N. Jazar [9].

In this section, a polynomial path will be formulated to connect a start pose P_0 and an end pose P_1 without considering the singularity and boundary conditions. The path is formulated as a function of a parameter u ($0 \leq u \leq 1$) with the understanding that it can be parameterized with respect to time t . The function of the nominal path can be expressed as:

$$P(u) = a_0 + a_1u + a_2u^2 + a_3u^3 + \dots + a_nu^n \quad (0 \leq u \leq 1) \quad (15)$$

Where, $P(0) = X_0$ and $P(1) = P_1$.

Where, the parameter n represents the number of degrees of the polynomial equation which is determined by numbers of constrains the function must fulfill. In order to finish the tasks faultlessly, the end-effector needs to move without velocity and acceleration when approaching the target poses P_0 and P_1 . Thus, a rest to rest path with zero acceleration at the start and end poses is considered in this path planning approach, i.e. the first, second and third derivative of the polynomial path at both initial and final poses must equal to zero. Those constrains are given by

$$\begin{aligned} P(0) &= P_0 & \dot{P}(0) &= 0 & \ddot{P}(0) &= 0 & \ddot{P}(0) &= 0 \\ P(1) &= P_1 & \dot{P}(1) &= 0 & \ddot{P}(1) &= 0 & \ddot{P}(1) &= 0 \end{aligned} \quad (16)$$

To meet these eight conditions, a seven degree polynomial path is used, which can be expressed as

$$P(u) = a_0 + a_1u + a_2u^2 + a_3u^3 + a_4u^4 + a_5u^5 + a_6u^6 + a_7u^7 \quad (0 \leq u \leq 1) \quad (17)$$

Substituting equation (16) into equation (15), gives the seven coefficients $a_0, a_1, \dots, a_7$ of the polynomial path, and the initial nominal path of the path planning approach given by equation (17).

Assuming that $X_0 = 0$, $X_1 = 100$, the sketch of the nominal polynomial path connecting these two poses. The second and third differential of the nominal path represents the accelerations of the nominal path respectively. As can be seen in the graph, the value of accelerations at the start point X_0 and end point X_1 is equal to zero, thus the end-effector will start and stop at the target poses without acceleration when moving along the designed path.

2.2 Serial optimization method

After a nominal polynomial path connecting the initial pose P_0 and final pose P_1 has been obtained, the path shall be optimized to avoiding the singularity configurations of the end-effector. In this section, an optimization method is developed for the hybrid parallel robot.

According to the kinematic analysis of the hybrid parallel robot, the poses of the end-effector along the nominal path are determined by the equation shown below:

$$P(u) = P_H(u) + P_T(u) \quad (18)$$

where $P_H(u)$ and $P_T(u)$ are the poses of the centre points of upper platforms of hexapod and tripod respectively. And the values of position and orientation variables of $P_H(u)$ and $P_T(u)$ are based on the global coordinate system.

By defining a proportional factor Δ for the equation (19), the poses of the hexapod and tripod manipulator can be obtained with respect to the poses of the end-effector, which is expressed as:

$$\begin{aligned} P_H(u) &= \Delta P(u), \\ P_T(u) &= (1 - \Delta)P(u), \quad \text{where } \Delta = \Delta_u \end{aligned} \quad (19)$$

Thus, initially, the path of the upper platforms of the hexapod and tripod manipulator can be expressed as:

$$P_H(u) = \Delta_0 P(u), \quad P_T(u) = (1 - \Delta_0)P(u). \quad (20)$$

While the end-effector moves along the nominal polynomial path, the poses of the end-effector will be checked with the singularity-free condition of the parallel robot, the condition has been obtained. When a specific pose is determined to be singular, an optimization method is developed to adjust the poses of both hexapod and tripod parallel manipulator. This method is referred to as "Serial optimization method". This method is designed to solve the problem of singularity by adjusting the proportional factor Δ of the hybrid parallel manipulator. Therefore, the pose of the hexapod $P_H(u)$

and the pose of the tripod $P(u)$ will be adjusted to support the singularity of the hybrid robot. Meanwhile, the end-effector will always stay at the same pose $P(u)$, and the nominal path for the end-effector will not be changed in this method. Thus, the smoothness and continuity of the seven degrees polynomial path are maintained in the final singularity-free path. This is also a practical advantage of the hybrid parallel robot described in this paper over the general type of parallel manipulators.

2.3 Detour optimization method

When the “Serial optimization method” fails to find a singularity-free path, then the pose of the end-effector has to be changed. In this category of situations, another optimization method, referred to as “Detour optimization method”, will be applied to generate a singularity-free path. The pose X_{via} will replace the initial singular pose on the nominal polynomial path. Therefore, this optimization method is designed to obtain a singularity-free path by optimizing the nominal path locally, and the final path will detour the singular poses presented on the nominal polynomial path. While the end-effector moves along the nominal polynomial path, the poses of the end-effector will be checked with the singularity-free condition of the parallel robot when a singular pose $X_{singular}$ is presented on the nominal path, a via point X_{via} will be obtained by applying a loop algorithm. During the procedure of the loop, intermediate poses will be determined to replace the singular pose on the nominal path, and the intermediate poses are given by optimizing the position variables (x, y and z) of the singular pose. The singular pose found on the nominal polynomial path is expressed as:

$$P_{singular} = P(u) = [x_u \ y_u \ z_u \ \alpha_u \ \beta_u \ \gamma_u]^T \quad (21)$$

Intermediate poses are found by changing the coordinate value of the singular pose starting from x, y and z respectively. Finally, a non-singular via pose is found, which is expressed as:

$$P_{via} = [x_{via} \ y_{via} \ z_{via} \ \alpha_u \ \beta_u \ \gamma_u]^T \quad (22)$$

The output of this detour optimization method is:

$$P(u) = P_{via} \quad (23)$$

Thus, after the procedure is completed, the singularity pose on the nominal path is replaced by a non-singular via pose. The nominal polynomial path has been locally optimized and becomes a singularity-free path for the end-effector. In this method a parameter ∂ is utilized to ensure that the via poses do not locates too far away from the singular pose on the nominal polynomial path. This parameter is designed to guarantee the smoothness of the final non-singularity path.

3 RESULTS AND DISCUSSION

A MATLAB program has been developed to implement the singularity-free path planning approach based on developed inverse kinematic analysis of the hybrid parallel robot. The step interval τ in the program is considered to be 0.01. A motion profile is applied to the software as an example to determine possible singularities. The developed program is applied for both hexapod and hybrid structures. Besides, after testing MATLAB program with various trajectories, the best value of the default proportional factor is determined to be 0.5.

$$P_H(u) = 0.5P(u), \quad P_r(u) = 0.5P(u) \quad (24)$$

The MATLAB program has been tested to generate singularity-free path with various poses in workspace, where one is shown below.

The planed path for the end-effector of the hybrid parallel robot starts from a start pose P_0 to a final pose P_1 , where, $P_0 = [10 \ 10 \ 10 \ 0 \ 0 \ 0]^T$, $P_1 = [100 \ 80 \ 110 \ 0.15 \ 0.25 \ 0]^T$. The determinant of the transformation matrix $II(X)$ and a path connecting these two poses has been generated by the path planning MATLAB program. After the singularity-free path is obtained from the MATLAB program, the CAD model of the hybrid parallel robot is utilized to validate the planned path. The path of the platform A by applied optimization method for hybrid parallel robot are compared with simulation data in Fig.3, 4 and 5 while obtained path of platform E in theoretical and simulation in X, Y and Z are demonstrated in Fig.6, 7 and 8.

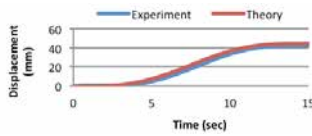


Figure 3: motion of Platform A in X-axis

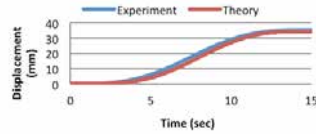


Figure 4: Motion of Platform A in Y-Axis

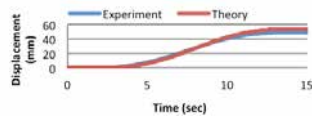


Figure 5: Motion of platform A in Z-axis

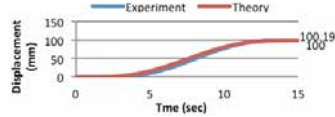


Figure 6: Motion of platform E in X-axis

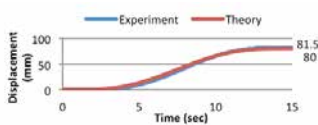


Figure 7: Motion of platform E in Y-axis

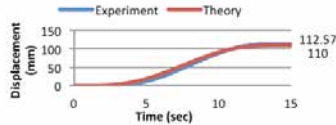


Figure 8: Motion of platform E in Z-axis

4 CONCLUSIONS

This paper addresses the developed path motion for new configuration of hybrid parallel robot. The developed polynomial path applied to inverse kinematic of system in order to calculate stroke sizes of actuators that were imported to CAD model. The theory developed for non singular path was successfully validated by obtained results from the simulation.

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MULTIPLE-SENSOR INTEGRATION FOR EFFICIENT REVERSE ENGINEERING OF GEOMETRY

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ABSTRACT

This paper describes a multi-sensor measuring system for reverse engineering applications. A sphere-plate artefact is developed for data unification of the hybrid system. With the coordinate data acquired using the optical system, intelligent feature recognition and segmentation algorithms can be applied to extract the global surface information of the object. The coordinate measuring machine (CMM) is used to re-measure the geometric features with a small amount of sampling points and the obtained information can be subsequently used to compensate the point data patches which are measured by optical system. Then the optimized point data can be exploited for accurate reverse engineering of CAD model. The limitations of each measurement system are compensated by the other. Experimental results validate the accuracy and effectiveness of this data optimization approach.

Keywords: Hybrid system, CMM, Reverse engineering.

1 INTRODUCTION

Even though tactile and optical sensing technologies are widely used in data acquisition in dimensional metrology, it has been shown that each technique has its own characteristics and limitations, which lend them to particular applications. On the other hand, due to the different measuring techniques and their physical working principles, different interactions between the workpiece and sensor occurs and different surfaces are captured (Weckenmann *et al.* 2000). The reduction of the lead time in RE, and the increased requirements in terms of flexibility as well as accuracy have resulted in a great deal of research effort aimed at developing and implementing combined systems based on cooperative integration of homogeneous sensors such as mechanical probes and optical systems (Chan *et al.* 2000, Carbone *et al.* 2001, Bradley *et al.* 2001, Sladek *et al.* 2011). However, until now no relevant study has been found about how to efficiently handle integrated measurement data in reverse engineering, in other words, how to use more accurate measurement information to improve the overall measurement accuracy.

This paper describes a flexible and effective approach for the integration and optimization of a 3D structured light system with dual CCD cameras and a CMM with a contact-probe to perform the reverse engineering of geometry. A sphere-plate artefact is developed for unification of the hybrid system and it does not need the physical integration of the two sensors onto the CMM, but includes their combination at the measurement information level. The system unification is achieved by measuring the spheres calibration board and then measurement results from combining all of the optical sensors and the CMM probe head into one set. With the coordinate data acquired using the optical system, intelligent feature recognition algorithms can be applied to extract the geometric elements of the object. These key features of elements can be re-measured using a small number of points by the tactile CMM and described by mathematical and numerical methods. The obtained information can subsequently be used to optimize the vast amounts of point cloud data measured by the optical sensor.

2 HYBRID SYSTEM CONFIGURATION AND CALIBRATION

2.1 Elements of The Hybrid System

The integrated system (see Fig. 1) is designed and manufactured with the following components as shown in Table 1:

Table 1: The Components of The Integrated System.

A	High accuracy CMM	Zeiss PRISMO system
B	Two CCD cameras	IDS UI-1485LE-M-GL, the CCD resolution is 2560(H)×1920(V), the dimension of a pixel is 2.2 μm ×2.2 μm
C	Lens	Fujinon HF12,5SA-1/1,4 5 Megapixel C-Mount Lens, the focal length is 12.5 mm
D	Projector	Panasonic PT-LB60NTEA projector with 1,024×768 pixels
E	Planer calibration board for optical scanner calibration and sphere-plate standard for unification of hybrid system	



Figure 1: The integrated system

2.2 Hybrid System Calibration

The CMM and optical scanner need to be calibrated separately before measurement to reduce uncertainty within their own coordinate frames. A master stylus is used for qualifying the CMM on a reference sphere and then a new stylus system must be qualified. The maximum permissible error of length measurement (MPE) is $(1.9+L/300) \mu\text{m}$ (ISO 10360-2:2009).

There are many studies concerning modelling and calibration of CCD cameras (Atkinson *et al.* 2003, Sheng-Wen *et al.* 1996, Sagawa *et al.* 2008). Camera calibration in the context of 3D optical measurements is the process of determining the transformation from 2D CCD image to 3D world coordinate system. In this paper Zhang's (2000) method is exploited to calibrate CCD cameras, the accuracy of 3D structured light system is up to 45 μm .

3 HYBRID SYSTEM COORDINATES UNIFICATION

3.1 Geometric Transform Method for Hybrid System Unification

The optical scanner and the CMM work in their own separate coordinate systems. If the integrated system is to produce useable results, these two coordinate systems have to be unified. The same position surface data of a workpiece scanned from an integrated system can be seen as a kind of rigid

body movement, so the geometric transformation method can be used to deal with coordinate unification. Since three non-collinear points can express a complete coordinate frame, data fusion of the two systems will be achieved simply with three different reference points and a three-point alignment coordinate transformation method. Therefore, the data fusion problem for an optical system and CMM is converted to a coordinate transformation problem, the coordinates of multiple scan data from both system can be transformed to one coordinate system.

Coordinate transformation of 3D graphics includes geometric transformations of translation, proportion, rotation and shear. The coordinate transform method by three points is derived by Mortenson and presented by Tao (2007).

3.2 Calibration Board Design

While using this method the question arises of how to select optimal match datum-points from two different sensors. It is usually very difficult to obtain the same reference point from two different sensors (CCD cameras and CMM in this case) because of the different measurement principles and methods of two systems as well as different point cloud density. If we take a reference feature point as the calibration reference point every time, the possibility of occurrence of system error, human errors and accidental errors will increase greatly. Because three points can establish a coordinate frame, we can consider calculating the centroid of a standard calibration ball and then use the sphere centre coordinate as the datum reference point coordinate to achieve data fusion and reduce fusion errors.

A ball-plate calibration board with three spheres attached to it is created for data fusion of the hybrid system. Three spheres form an approximate equilateral triangle and are made of solid polypropylene with a matt finish and have good roundness and sphericity with nominal diameter $\Phi=25.4\text{mm}$ and form error no greater than $\Phi=30\text{ }\mu\text{m}$. The coordinates of spherical centres measured by CMM and optical scanners can be calculated by least squares best fit method.

3.3 Mathematical Model of 3D Cartesian Coordinate Transformation

Suppose two 3D Cartesian coordinates $O-XYZ$ and $O_T-X_TY_TZ_T$, in space Cartesian coordinates transformation process, first the origin O is translated to another origin O_T along the direction of X , Y and Z subsequently, then two coordinates that have same origin can be transformed into the same one through three rotations. The transformation relation can be described by equation (1):

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_T = \begin{bmatrix} x_o \\ y_o \\ z_o \end{bmatrix} + kR \begin{bmatrix} x \\ y \\ z \end{bmatrix}_O \quad (1)$$

Where $\begin{bmatrix} x & y & z \end{bmatrix}_O^T$ is the coordinate in $O-XYZ$ and $\begin{bmatrix} x & y & z \end{bmatrix}_T^T$ is the coordinate in $O_T-X_TY_TZ_T$; $\begin{bmatrix} x_o & y_o & z_o \end{bmatrix}_O^T$ is three translation parameters, R is rotation matrix and k is scale factor.

$$R = \begin{bmatrix} \cos \beta \cos \gamma & -\cos \beta \sin \gamma & \sin \beta \\ \cos \alpha \sin \gamma + \cos \gamma \sin \alpha \sin \beta & \cos \alpha \cos \gamma - \sin \alpha \sin \beta \sin \gamma & -\cos \beta \sin \alpha \\ \sin \alpha \sin \gamma - \cos \alpha \cos \gamma \sin \beta & \cos \gamma \sin \alpha + \cos \alpha \sin \beta \sin \gamma & \cos \alpha \cos \beta \end{bmatrix} \quad (2)$$

Then there are 7 parameters x_o , y_o , z_o , α , β , γ and k , at least three pairs of coincidence points (9 known values) are needed to solve these parameters. The fitting function of spatial coordinate transformation 7 parameters problem is a matrix function, we can consider convert it into a non-linear over determined equation group, take space coordinates of 3 reference points to compose 9 over determined non-linear equations, then exploit non-linear least squares method to solve these 7 parameters.

4 DATA OPTIMIZATION BASED ON CMM MEASUREMENT RESULTS

4.1 Proposed Solution

After coordinate system unification, the optical and CMM measure in the same absolute coordinate system. However, two data sets measured by different sensors are unlikely to coincided absolutely, which means there must be a measurement error between the optical and tactile system. To overcome this problem, a data optimization method is proposed to enhance the measurement accuracy of the optical structured light sensor for RE. We are only interested in industrial samples.

After a part is measured, the acquired point cloud data should be divided into several smooth regions for surface fitting purposes, which is called the segmentation process (Woo *et al.* 2002). A segmentation that extracts the edges and partitions the 3D point data plays an important role in fitting surface patches and applying the measured data to the manufacturing process.

Planes, spheres, cylinders and cones are ubiquitous in the shapes of industrial components. In fact, more than 70% of the functional parts in precision machines can be modelled using these simple shapes (Zhang *et al.* 2012). In RE, the final CAD model accuracy depends on the measured point data. Then, a small amount of discrete point data measured by the CMM can be used to ‘optimize’ massive point cloud data that has been measured by the optical scanner to improve the overall measurement accuracy. The specific method follows these steps:

- 1) Use the optical system to scan the workpiece to digitize the entire surface; and then a segmentation algorithm is exploited to obtain the point data patches with geometric features;
- 2) Use the CMM to re-measure these geometric features with a small number points, and then use the least square method to best-fit these geometric elements and derive an equation to describe these elements;
- 3) Substitute x and y coordinates of points measured by the optical sensor into this equation then the new z coordinate can be derived; and then use x , y and new z coordinates as new point data coordinates to reconstruct the CAD model.

The new workflow of an RE workpiece by using hybrid contact-optical measuring system can be expressed as in Fig.2.

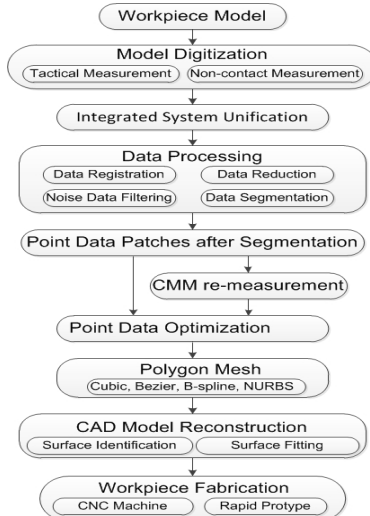
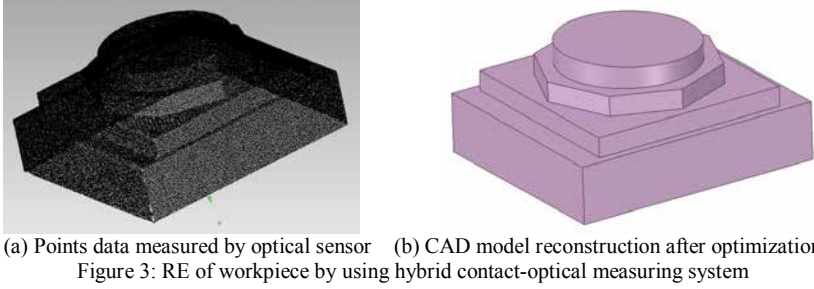


Figure 2: Workflow of RE by using hybrid contact-optical measuring system

4.2 Example Application

The method was applied to optimize point data measured by an optical sensor to reconstruct the workpiece CAD model in RE (see Fig. 3).



After data segmentation, this model contains only two types of geometric elements: plane and cylinder.

A spatial plane is specified by

$$Ax + By + Cz + 1 = 0 \quad (3)$$

There are three unknowns in this equation. By using the point data measured by CMM (see Fig.4 (a)) and using the least square method, these parameters can be solved. To substitute x and y coordinates of points measured by optical sensor (Fig.4 (b)) into this equation (3), then the new z coordinate can be derived and new point data coordinates are used to reconstruct the polygon model.

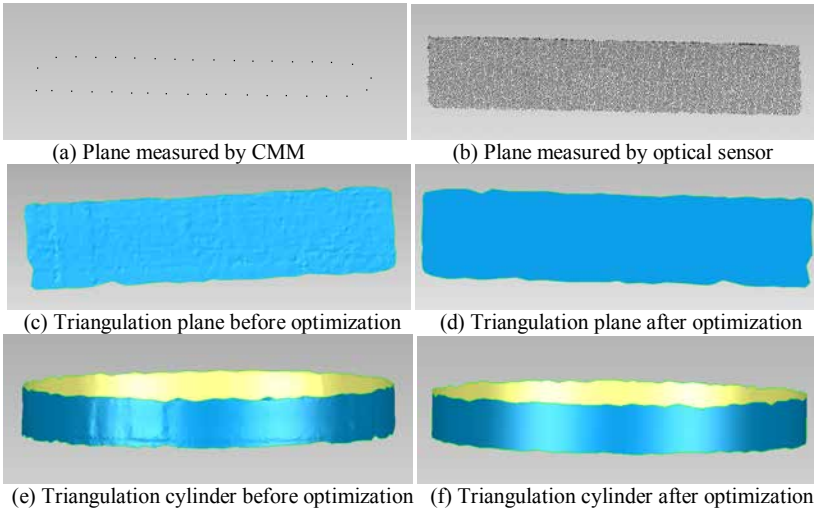


Fig.4 (c) shows the triangulation mesh plane generated by original un-organized point cloud data which is scanned by the optical sensor, Fig.4 (d) shows the new triangulation mesh plane after optimization. The new polygon model is very smooth as every point falls exactly onto the plane according the equation (3).

A cylinder is described by the direction cosines of its axis (m, n, l) , a point on the axis (x_o, y_o, z_o) and the radius r . We use the Levenberg-Marquardt algorithm (Shakarji *et al.* 2012) to obtain estimates of these parameters. Fig.4 (e) and Fig.4 (f) show the triangulation mesh cylinder before and after optimization, respectively. The accuracy and quality of point data on the surface have been greatly enhanced. The rough edge on the cylinder (Fig.4 (f)) could then be improved by constraining with projection of the measured planes.

5 CONCLUSIONS

The development of a multi-sensor integrated coordinate measuring system for rapid and high-precision reverse engineering has been introduced. In current implementation, the multisensory system consists of a high-precision scanning CMM and structured light scanning system. A sphere-plate artefact with three spheres has been developed for unification of the hybrid system. With the millions of points acquired using a structured light optical scanning system, intelligent feature recognition and segmentation algorithms can be applied to extract the global surface information of the object. Then the CMM is used to re-measure the geometric features with hundreds of sampling points. The obtained information can be subsequently used to optimize the point data patches which are measured by the optical system. Theoretically, after optimization the data measured by optical sensor has same accuracy as the CMM (depending on the accuracy of geometric characteristics of sample pieces). The experiment results show this novel approach is accurate, convenient and reliable. The principles presented can be further extended to include other geometric features, such as cone, torus and elliptical cylinder etc.

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HUMAN VARIABILITY, TASK COMPLEXITY AND MOTIVATION CONTRIBUTION IN MANUFACTURING

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ABSTRACT

This paper is a preliminary study of the human contribution to variability in manufacturing industry and how motivation and learning play a key role in this contribution. The longer term aim is to incorporate this understanding in a methodology, using principles and guidelines, that aims to help in the design of intelligent automation that reduces product variability. This paper reports on the early stages that are concerned with understanding relationships between human-induced product variability, task complexity and human characteristics and capabilities. Two areas have been selected for initial study in manufacturing industry: (a) the relationship between manual task complexity and product variability and (b) the relationship between employee motivational factors and learning behaviours. The paper discusses the progress to date in conducting initial empirical studies and surveys in industry and draws tentative conclusions of the value of this knowledge to the overall objective of intelligent automation.

Keywords: Human variability, Motivation, Manufacturing Automation.

1 INTRODUCTION

The UK manufacturing industry is the sixth largest in the world and it is a significant contributor to the UK's GDP (Gross Domestic Product). The UK Aerospace and Defence industry is the second in the world, accounting for \$40bn of annual sales and the UK has the third largest automotive industry in Europe, with total sales of around £9bn (11% of the UK's total exports) (Pricewaterhouse 2009). Humans play a key role in manufacturing processes and this role has been changing through the years due to advances in technology but also due to globalisation and social changes. Automation in manufacturing has replaced some dangerous, mundane, arduous and routine manual operations. For example, transportation of heavy parts, stamping large parts, repetitive welding and monotonous assembly processes are no longer performed by humans. In contrast, skilled operators carry out critical tasks in different industries such as aerospace, automobile, heavy-machinery and renewable energies, being an essential part of the production processes. Limited automation has been applied in high-value manufacturing companies because of the extremely skilled nature of the work embedded in the tasks. The mix of human factors such worker skills, experience and decision-making capability involved in these complex tasks plus the high-value parts being handled in the processes make these notably difficult to automate. Understanding how humans perform complex tasks will help to reduce variability in products/outputs, to design future processes and eventually, to achieve more appropriate automation solutions. Many manual operations, such as inspection, adjustment and rework do not add value to the final product, and hence it can be said that these operations are fruitless. If these operations can be eliminated from the production process, the productivity and competitiveness of UK industry will increase. Furthermore, employee motivational factors and learning behaviours are important contributors to product variability and thus will affect job satisfaction and turnover in manufacturing industry.

2 LITERATURE REVIEW

Human Variability

In production management, variability is suggested as a main cause of lack of robustness in the production process. Some of the most common sources of variability are process equipment capabilities and calibration limits, raw materials, sampling variability, environmental factors and human factors within the plant facility (Glodek *et al.* 2006). In addition, other factors affecting human variability include social and organisational factors (Govindaraju, Pennathur and Mital 2001). All these factors can be grouped into three main sources of variability: Component, Process and Human. The aim of this research is limited to human variability although all three are highly linked and studying the human contribution to variability without inferences from components and processes is one of the biggest challenges to be faced in this study.

It is well known that in manufacturing environments humans can adapt and “readjust” to variation in materials and processes, making decisions according to these variations and consequently, perform tasks that otherwise would be impossible to be finished with the established time and quality standards. However, humans can also introduce variations in the process by the mere fact of being humans (Sandom and Harvey 2004).

Human variability in manufacturing can be described as the capability that humans have for performing the same task in different ways. This variability is found between different individuals with a range of internal and external factors. Internal factors are (among others): age, gender, race, culture, education, physical condition, tiredness, motivation, social factors and human relationships inside and outside the workplace. External factors are, for instance, environmental conditions (light, cold, noise) or constraints (time, space). These sets of factors will play a fundamental role in how a worker develops a specific task and it can result in a variability of performance and outputs during the work shift. This set of factors will also determine significant differences between operators working under the same conditions. It is claimed that variations in human task execution can be found even with the limitations and control imposed by job simplification and automation in modern manufacturing systems (Osman 2010). The influence of complex tasks on human behaviour and disparity of output has become of more interest in recent years. The more complex a task is the more likely dissimilar results will be obtained because it demands more attention and effort. More effort can also be required when the subject is fatigued or works under extreme environmental conditions (Backs and Boucsein 2000).

The nature of complex manual processes means that cognitive aspects related to decision making play a fundamental role in understanding human variability. Klein and Zsombok (1991) suggested that people use their past experiences to make better comparisons and decisions. They further argued that when the situation is familiar, the decision makers may never have to contemplate options (Klein, Calderwood and Clinton-Cirocco 1986). Based on this, novice decision makers could be taught to recognise typical cases, and to identify when cases were not typical, in order to supply a picture of the distribution of situations (Tversky, Kahneman, and Slovic 1982). Furthermore, the first option contemplated by experienced decision makers is usually acceptable. It was found that decision makers (chess players in this case study) can produce reasonable choices initially, using their experience to construct the option generation process (Klein *et al.* 1995). This option generation process occurs in an organised, not by chance, manner. A major conclusion of the study is that even moderately experienced people can generate feasible options.

Due to the complicated interactions of humans, processes and component variability, it is unclear when automation could be beneficial, i.e. in reducing variability caused by the operators during a manufacturing process. Therefore, understanding the human’s role in these processes will help to decide which tasks are suitable to automate and vice versa.

It can be seen that human variability is a complex problem. The aim of this research is try to understand which human attributes and what kind of situations or circumstances will be likely to introduce variability in complex tasks within the manufacturing process. If the precise reasons for variability can be identified and studied, it would be possible to eliminate them from the process by incorporating this knowledge in the design process.

2.1 Motivation and Learning Curves

Employee demotivation is related to job dissatisfaction and therefore changing job intention in many organisations. Some organisations motivate their employees by offering them rewards for satisfactory performance and for working more effectively towards their organisational goals (Elding *et al.* 2006). Several theoretical frameworks have been developed and used to explain the issue of employee motivation and job satisfaction. The concept of job motivation or employee motivation is broad and complex, and many scientists have agreed its basic characteristics and defined motivation as “the set of processes that arouse, direct and maintain human behaviours towards attaining goals” (Bent *et al.* 1999).

According to Ullah Khan *et al.* (2010) employees should motivate themselves to work hard to satisfy their personal goals as well as the organisational objectives. Therefore in this competitive world it is a challenge for the management to motivate them to offer very good services for customers. This aligns the individual personal goals to those of the organisational goals. Locke and Latham (1984) in their goal-setting model predict that employee motivation and performance will increase if they have clear goals. Many scholars suggest that employee motivation and vision is positively affected by organisational learning, while others found that organisational learning is positively affected by the vision and motivation of the employee.

There are many approaches to motivating employees, teams and organisations. Hitka (2011) mentioned that some of them are focused on rationality and orderliness, with for instance employees being required to do more difficult or complex tasks. In this very competitive business environment, one of the biggest challenges that managers face is the use of employee motivational techniques to achieve their business goals. It is suggested that the most influential tool to successful strategy execution is the proper design of reward structures that will motivate the employees (Thompson *et al.* 2005).

There is still debate on which rewards really motivate workers but money is not the main factor as Barrier (1996) suggested. He claimed that the stronger motivator of employee performance is showing appreciation rather than giving monetary incentives. Not only that, many practitioners agree that jobholders are more concerned about their recognition and job security compared to financial rewards. Jamalmohammadi *et al.* (2012) in their study on the relationship between employee motivational factors and efficiency concluded that for directing employee motivation in an organisation, managers should consider the fundamental nature of work as this will affect the success of employees more than other factors. Factors include an equal and fair reward system, work incentives, inspiration, promotion and career advancement, and also interaction between staff and environment leading to efficiency.

There have been many studies in industries such as automotive, aerospace, construction, electronic and software to measure employee performance in new and repetitive tasks. An efficient tool to monitor performance is learning curves (LC) theories. Wright (1936) proposed this theory to observe cost reduction due to repetitive tasks in production plants. There are several factors that will impact on the employees' learning process such as training program structure, employee motivation, experience and task complexity and these factors can be analysed using LC theories (Anzanello and Fogliatto 2011).

Guimaraes *et al.* (2012) applied the LC model to measure whether rotation of different task complexities will affect the employee learning rate and performance. The intervention was shown to reduce accidents in the workplace by 80%, reduce absenteeism by 45% and also eliminated work related to musculoskeletal disorders, medical conditions as well as increasing turnover. The output rate of the multifunctional team increased by an average of 3% compared to production rates using the Taylor/Ford system (Guimaraes *et al.* 2012).

Based on the literature, little work has been done on either relating motivation theory to learning or the ultimate impact on product variability. The next section discusses the progress to date in conducting initial empirical studies and surveys in industry and draws tentative conclusions of the value of this knowledge to the overall objective of intelligent automation. There is a need to study the relationship between employee motivational factors and learning behaviours in manufacturing process. It is hypothesised that learning by doing different tasks whether they be simple or complex will impact on employee motivational levels as well as increasing job satisfaction and reducing employee turnover.

3 RESEARCH METHODS

3.1 Variability and Task Complexity

A preliminary pilot case will be conducted in order to determine: what is a complex task, what attributes/constraints make a task complex, what human factors are important and how they vary between operators. The initial hypothesis suggests a high correlation between task complexity and human variability. After a first phase of observation, information collection and Cognitive Task Analysis, a general understanding of task complexity in high-value manufacturing processes will be obtained. Based on this understanding controlled experiments will be designed in order to discover the relationships between task complexity and human variability. A pilot case is being conducted in the laboratory to test the initial hypothesis of the influence of task complexity. The purpose of the pilot study is to analyse three task attributes that are suspected to be responsible for facilitating people to introduce variability, these are: number of required actions to complete the tasks, number of components needed to complete the task, information received in order to complete the task (clarity of instructions, conflict between steps, repetitiveness, change of goals).

This pilot study consists of assembling a LEGO® Mindstorm robot. The pilot experiment will have two phases: In the first phase, the subjects are presented with clear instructions in how to assemble the robot. Future stages of the experiment will ask the subjects to assemble the same model of robot but using deficient instructions. Timing and checking the output comparing with the model, the pilot experiment will be able to show what the personal differences are within the same individual performing the same robot model with full assembling instructions, 70% of the instruction steps and 30% of these steps. The differences (time and final output) among subjects will be also noted. Hopefully this first stage of the pilot experiment will prove that lack of information or unclear instructions for executing a task will lead to variability in cycle time and final product.

The second phase of the pilot experiment will present different LEGO® models to be assembled, increasing the number of components in the models. The experiment tries to prove that the bigger the number components needed to perform a task, the bigger the human variability will be (variations in cycle time and final product). In this case, clear instructions will be presented to all subjects. Initially, the number of components and number of actions are considered to be related, because in this experiment the number of components to be assembled cannot be increased without increasing the number of actions needed in order to complete the task.

Learning curves for subjects have been considered and the effects are expected to be counteracted with the sequence of the experiment, going from easier assembly task to more complex, in the task where subjects are assembling the same model. In this case, complexity is added by reducing the information provided for assembly. In order to minimise the learning curve effect this task has also been programmed with two weeks difference to allow subjects to forget what they learned first time.

If the data collected from the pilot experiment proves that a lack of information and increasing the number of components will lead to higher differences in human performance, this experiment will be tested in actual manufacturing processes. The plan is to start with simpler tasks and then to increase the complexity by adding controllable external factors to observe how individuals respond to stimuli augmentation. Starting with number of components, number of actions and clarity of information, other task factors could be also added to the experiment (dynamic change of inputs, time constraints, more than one acceptable output...). Variability will be measured by means of dimensions, cycle time, missing parts, deficient assembly and any other non-quantifiable attribute considered important from a quality perspective (for instance external appearance). The anticipated outcome from this research is a comprehensive scheme which will help engineers and process designers to understand sources of variability when humans perform complex tasks.

3.2 Motivation and Learning Curve

Pilot case studies will be conducted at Loughborough University and the Technical University Melaka Malaysia by inviting students and technical staff to participate. A particular aspect of the investigation will focus on the differences in skilled and unskilled students and staff. These findings will be used for the design of real industrial cases studies. Some case studies will be designed to derive the

relationships of variability induced by human operators during tasks and the outcome of the process. The process outcome may be related to the short or long-term implications in terms of the quality of finished products, the impact on learning curves of the employees, etc. Case studies will be conducted in manufacturing by means of digital surveys including multiple-choice and open-ended questionnaires distributed to employees in order to understand the contribution of human operators to variability in manufacturing/assembly operations. Video cameras will be used to capture the capability of skilled and unskilled employees during the process of the manufacture or assembly of products with different complexities. The human resource managers/advisors of the industry will be approached to participate in the study. Respondents will also be asked to complete the hard copy or digital questionnaires that are sent through their email or via their human resources managers/advisors. This survey aims to measure the relationship between the motivational factors and learning behaviours of skilled/unskilled workers in doing the simple/complex tasks as well as the effects on job satisfaction and employee turnover.

4 CONCLUSIONS

A long-standing problem has been to identify and describe the types of human variability and how they affect manufacturing processes and, reciprocally, how human variability is affected by manufacturing processes. Variability in procedures adopted by the operators may contribute to process variability and hence be transmitted to final outputs. The importance of this research is based on understanding how operators behave when they are dealing with variability from parts and processes in complex manual tasks. It will also identify task characteristics that impede people in adapting to and, to a certain extent, correcting this variability. The initial literature review suggests a high correlation between task complexity and variability. After the completion of the pilot study, a general understanding of some task characteristics and how they affect human performance when executing complex assembly tasks will be obtained. Based on this initial experiment, other experiments will be designed in order to acquire a deeper knowledge about task complexity factors and their influence on the behaviour of humans during real manufacturing processes.

At this stage of the research, it seems that studying task characteristics affecting human performance and proving that some of them negatively influence humans in trying to achieve the desired outcomes may be feasible. The biggest challenge to be faced in this project is to capture how humans adapt to external variability, and in detecting what capabilities (mainly cognitive) are used when performing complex tasks. In addition, extrapolating these findings in specific complex tasks, even if they are actual manufacturing processes, to other manufacturing processes appears risky. It can be claimed that one task characteristic impeding human in reducing part and process variability might not have the same effect in another process.

In addition, the topic of work motivation needs to be explored broadly, as several recent articles have examined how far researchers have come with work motivation, which leads to open questions such as: What is the future work motivation theory? What is the future research agenda? How can we extend or modify the current models so they continue to be relevant in the future? And what are the new model of employee behaviours and job performance in contemporary organizations? These are an example of the challenges for researchers to explore in broader view not only focussing on the work motivation theory but also the relationship between learning behaviours in the workplace. In a very recent study Guimaraes et al. (2012) found that future development should include the learning curve (LC) modelling in training procedures to evaluate their efficiency toward multifunctional and teamwork. The LC modelling will also be used to define an optimal sequence in task rotation aimed at maximizing production levels and worker's satisfaction. It is also suggested by Egan et al. (2004) that future work should include longitudinal studies that measure perceived organizational learning culture, critical incidents and employee motivation, and also comparative studies examining differences and similarities between organizations and relevant outcomes. Further investigation should be made regarding these matters and we should be extremely cautious when presenting conclusions of experiments. The research findings will be incorporated into a methodology to aid the design of automation solutions.

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**INSTRUCTIONAL FACTORIES AND TRAINING COURSES:
THE INCEPTION AND IMPLEMENTATION OF TRAINING COURSES FOR
UN-SKILLED AND SEMI-SKILLED MUNITIONS WORKERS
DURING THE GREAT WAR**

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ABSTRACT

The Great War shell scandal of 1915 was as much to do with a lack of skilled workers as it was to do with the early inability of the Munitions Industry to manufacture the war materials required by the war. The number of skilled workers had never been large and volunteering for the Army on a large scale had drastically reduced that pool. Attempts to avoid ‘dilution’, or the use of un-skilled and semi-skilled workers, particularly women, in the munitions industry in the early months of the Great War failed. The Volunteer Scheme was an initial disaster for the newly created Ministry of Munitions. Recalling skilled men from the Army failed in equal measure. The only way for the Ministry to plug the skills gap, was to bring in semi and un-skilled workers. In 1916/17 Technical Institutes like Loughborough and Aston began to run short training courses for workers.

Keywords: Workforce, Training, Productivity

1 INTRODUCTION

In spite of the failure to obtain skilled workers, there was a pool of manufacturing ability in the country. Many of the women, youngsters and wounded soldiers who joined the workforce became just as skilled, able and energetic as the men. Munitions work consisted mainly of repetitive operations to manufacture standard articles in large quantities. Hence, standardised, mass production was required. In pre-war days, there had been comfortable markets and the “conservative habits” of the skilled worker in the workshop ensured that the production of articles could be switched as required but output was small and slow (HMSO, 1920). The war machine needed standardised items, produced on a vast scale and quickly. Investment was not a bar, wage demands could be met, new machines and devices for speeding up production could be designed, tested by skilled engineers and scientists. Importantly, training for the new workforce could be paid for, improved and expanded.

2 THINKING ABOUT PLUGGING THE SKILLS GAP

As the Ministry came into being forward thinkers in educational establishments and in the government were considering the speedy training of semi-skilled workers for munitions work. Technical Colleges, Institutes and schools were obvious places to train the new workforce but many were not well enough equipped with modern machinery on which to train. Some had possessed modern equipment but had been forced to hand it over to the new munitions factories. There was a shortage of skilled tutor/instructors because such educational personnel with industrial experience were either already involved in manufacturing in the war work factories or in the forces. In addition, because of the nature of the pre-war courses that they ran a number of the Technical Institutes and colleges had not employed such skilled staff in the first place. Among other courses, the Technical

Institutes ran domestic, art, commercial and Volunteer Aid Detachment courses (Loughborough, 1915).

3 VOLUNTEERS

Professionals and tradesmen from industries and trades suffering a downturn because of the war came forward in large numbers to do their bit. It was to the Technical Institutes, colleges and schools that these people applied for training courses. The Ministry was keen to employ those who had some skills rather than the un-skilled who also came forward to help, for a number of reasons. Firstly, *if* they could be trained up they would quickly fill the skills gap. Secondly, as already skilled in another field, they would not irritate the unions and after the war they would go back to their old jobs and professions and not clog up the engineering labour market.

4 FACTORY TRAINING

The problem with current training in this area was that it was based upon the traditional and lengthy apprenticeship system learned on the workshop and factory floor. It was known that employers would favour those who had trained in the traditional fashion in the factory above any worker who had been on a training course at an educational establishment. This was despite the facts that those coming forward, clamouring to train as munitions workers were often intelligent, adaptable and very well motivated to do the job. The educational establishments were having to turn these people away because of a lack of machinery and tutors. Not every Technical Institute had a training syllabus in place and there was a worry that even if the volunteers were trained the factories would not take them on. The Technical Schools and Institutes “could have been filled many times over in the summer of 1915” but they were not (HMSO, 1920). While it was trying to attract skilled men from private firms, the Ministry had been looking for volunteers in the wrong place.

5 INITIATIVE BY EDUCATIONAL ESTABLISHMENTS

In the late spring and early summer of 1915, some Technical Institutes, Local Education Authorities and Munitions Committees took the initiative, not the Ministry. Technical Institutes at Birmingham and Aston were the first to go ahead and collaborating with the local munitions committees ran their own training courses for munitions workers. They proved a point. The trainees or students turned out to be excellent material, making a deep impression upon those who did employ them. It was obvious that if only the resources could be found and attitudes in certain quarters could be changed then the nation possessed a large labour resource.

On 26 June, inspired by the work at Birmingham and Aston, Sir R. Blair informed Dr. Addison that the Metropolitan Munitions Committee of London intended to give an order for the manufacture of gauges to the Polytechnics in the area and that the local Technical Institutes would provide some training courses (for munitions workers). Blair requested that he be put in touch with someone in the Ministry who could specify what kind of training was required. He sent a report made by the London County Council to the Ministry highlighting the good work being done by the Birmingham and Aston Technical Institutes in this training area.

6 GOVERNMENT AND MINISTRY CONTROL

As a result, Dr. Addison decided that the best Technical Schools and Institutes should start training courses and be given contracts for small quantities of shells to allow the students to train. Other schools and institutes that were not deemed good enough would have to give up any of their remaining machinery to the National Factories. This distinction could make or break an educational establishment. Early in July the Ministry contacted the Board of Education about training and stressed the need to train workers. The Technical Institutes, the Munitions Committees and the Local Education Authorities already knew what was required of them.

The courses being run by the Technical Institutes were between 20 and 120 hours in length depending upon the equipment that the students were training to operate. Short courses trained students specific operations on specific machines, longer courses offered similar training along with

bench work and more specific skills. The Ministry advised the Institutes to contact their local munitions factories to ascertain what type of workers were needed so that they could tailor the courses accordingly. All of the training was to be certificated and all of the courses were eligible for grants from the Board of Education.

The Ministry appointed Mr. T. M. Taylor and Labour Officers to oversee the project and co-ordinate the educationalists. They were also to make it plain to the employers and unions that workers of "superior education" from other skilled jobs and professions would be trained and offered up for placement. These workers, at the end of the war, would return to their own work. They would not clog up the labour market or cause trouble for industrial relations. The Labour Officers also had to obtain information about the Institutes and schools themselves.

7 FINANCE FOR THE PROJECT

The question of finance was addressed and on 17 September 1915 the Ministry approached the Treasury asking that the following be sanctioned: The salaries of teachers at the Institutes be paid while undertaking this instructional work. The heating, lighting and cleaning costs of the Institutes be covered. The cost of damage to the premises and equipment would be paid if required. A financial allowance be made available and met for depreciation of plant. The cost of providing, re-setting or re-assembling plant for training purposes be met by the Ministry. These demands were agreed on 28 September. Funding for the project, at least, was in place.

8 REPORTS ON WORK ALREADY UNDERTAKEN

It did not take long for Taylor's Officers to return their findings about the work already undertaken and the opinions of the industry. Courses had sprung up all over the country; some had been successful and their students had been placed in munitions factories. At these institutes the courses had been well planned and well taught and the employers were satisfied. Other courses fared less well. Some classes were cancelled before completion. In some cases students had been trained but had not been placed. Some courses were too academic; others were not in touch with the latest working practices and machines. Some courses failed because the quality of teaching was poor. In some cases employers were apathetic to the work of the Institutes or hostile to the whole project. In some places where workers had been placed, they left because of the hostile attitude of workers, foremen and unions. The Ministry and the educational establishments recognised that if this attitude could not be overcome then the training program would be compromised with disastrous consequences for munitions production. When reticent employers were quizzed about their attitudes they said that they thought the training provided would be inadequate. In many employers' opinions, a week's training on the job in the factory was worth a month on a training course. Others said that if they wanted operatives for repetitive machine work they could obtain women from textile mills who could already run machines. Institutes were advised to take students from non-skilled and non-professional backgrounds to increase the pool of workers. This worried the educational establishments. They liked bright and adaptable students because they learned quickly, graduated on schedule and were less likely to damage expensive and valuable equipment.

9 PUSHING ON WITH THE PROJECT

Despite opportunities offered by factories for volunteers to start on the shop floor and learn there, some volunteers wanted a grounding in their new work before they plunged into factory life. Because of this the Technical Institutes and Schools said that they were the best entry point for those volunteering to work in munitions.

For the training program to run efficiently employer's concerns had to be addressed and Herbert Schofield, the new head of Loughborough Technical Institute came up with the solution. The training given and learned had to be of the highest quality and Schofield had already decided that the training had to replicate that of learning on the job in the factory. There would also have to be close co-operation with the factories where the qualified students would go to work. His plan was "Training on Production" Both the Ministry and the employers eventually approved of it.

10 SCHEME FOR TRAINING SEMI-SKILLED WORKERS FOR MUNITIONS WORK AT TECHNICAL INSTITUTES

On 5 November 1915, a memo was circulated around the Technical Schools and Institutes. Essentially the Schools and Institutes would indeed train up semi-skilled workers for munitions work. The successful courses and educational establishments had convinced the Ministry that this type of training was viable and would succeed. The main bulk of the training courses nationally would concentrate upon semi-skilled work unless Institutes were involved in the training of skilled workers such as gauge makers and tool setters. Although the training was to be centrally controlled the Ministry did not lay down a rigid set of regulations instead a list of guidelines was set out.

If the Institutes wanted to access the funds available for the training courses they had to adhere to the guidelines and all training had to be practical. Two elements of the training had to be left out. There was no academic learning or bench work; both took too long. Where female students were taken on assurances of their placement had to be gained before they began training. Heads of Institutes and their staff were encouraged to liaise closely with the factories to ensure that the best co-operation was possible. Their out of pocket expenses were guaranteed and the financial arrangements and benefits for the Institutes who involved themselves in this training, mentioned earlier, were laid out. Schofield, knowing that University College Nottingham was over-flowing with student applicants to train as shell-turners, immediately saw that Loughborough Technical Institute could be part of this project and he saw the possibilities for his establishment.

11 LOUGHBOROUGH TECHNICAL INSTITUTE

Schofield admitted that his plan was not new. What was new was the process and it was, in the main, what the factories required. Loughborough Technical Institute was going to train students to semi-skilled level while working on genuine production of shells. They would learn to turn shells in the manner prescribed by their future work place and on the type of machines that they would eventually use. The Institute would become a small factory whose final product would be trained munition workers. The small number of shells manufactured would be a useful by-product. It would seem that the notion of the "Instructional Factory", and it was a title that Schofield always claimed as his own invention, had its genesis in Loughborough sometime between December 1915 and January 1916. Not in September 1916 as claimed by the Ministry.

In December 1915, while second hand machinery was sought for the Institute's workshop, Schofield managed to forge the beginnings of a close relationship with the industry he sought to help (Foden, 2007). During a visit that month, he was able to persuade Cammel Laird in Nottingham, who were sceptical, to give him a contract for a small number of 18-pounder shell bodies (Loughborough, 1915). In return he offered to train and supply them with 500 semi-skilled shell turners. This was the beginning of close contact between training establishment and factory. This was exactly the kind of integrated approach that the Ministry wanted and it worked. On 31 January, after a frantic month during which the staff created a workshop space and installed and repaired the second hand machines sourced from the local area, the first thirty female students arrived and began training under the tutelage of Schofield and his small staff.

12 THE TRAINING COURSES

To begin with, two courses, known as a double shift system, ran at the Institute. On the day course, thirty students were trained at a time. They undertook a two-week course that amounted to some 40 hours practical tuition about how to turn shell bodies on lathes. The evening/night shift, learning the same skills, was for groups of between 17 to 28 local women. In line with the Ministry's advice there was a caveat to joining the course. All students had to undertake to go into munitions work on completion of their course.

Many students arrived with no industrial background at all. During 1916, to assist the training course, Schofield and his colleague Driver wrote and published a handbook about shell turning (Schofield & Driver, 1916). It was intended that the students read the book and it was on display in the canteen. The book is really 'turning for beginners' and seeing that no written evidence of the

training curriculum exists at Loughborough University this book, now reprinted, is the only surviving written documentation of the course. It is, in effect, the training course for semi-skilled shell-turners.

13 THE SYLLABUS

The short course was divided into the following sections and the following is what the students did in their two-week course.

1. Instruction about lathes. The students were introduced to lathes and they were explained in general and simple terms and they were introduced to common terms and names. They were instructed from the simple to the complex; the engine lathe, the semi-automatic lathe and the automatic lathe. In the case of the latter, the students were informed that these lathes were intricate in design and required skill to set up. By way of encouragement (or goading) they would be told that a boy once he had mastered this type could run several at once, on his own...
2. Shell-turning. This was the core of the syllabus. They learned the processes of centring, boring and turning, facing and recessing.
3. General hints for good working practice and care of the machines. In this part of the course they were taught about lubrication, cleaning, what protective clothing to wear and they were warned about getting into bad habits with the machinery.
4. Instruction about cutting speeds.
5. Instruction about cutting tools.
6. Engineering measurements. The need for accuracy and the methods of measuring was taught but because of the repetitive nature of the student's work, they were made familiar with limit gauges.
7. Measuring instruments. The students were introduced to the different kind of measuring instruments that they would come across in the course of their work.

14 SUCCESS FOR TRAINING

It would seem that as the course progressed, the students were split into groups of six and while some were turning, others were put on boring and finishing. They rotated through the tasks (Rotherly, 1960). The Ministry took note of the course run at Loughborough, very much approved of the programme and it was claimed that the Loughborough Technical Institute was much admired. In this way 400 women semi-skilled munitions workers were trained by the Loughborough Instructional Factory and absorbed by Cammell Laird's between the end of January and April 1916. Cammell Laird's were delighted with the quality of the workers that Loughborough produced and requested more. Based upon this success, as time and the war went on Loughborough, like other educational establishments, began to offer more and increasingly skilled courses in other fields of munitions production and aeronautical work.

15 OPTIMISM AND DISSENT IN GOVERNMENT AND EDUCATIONALISTS

By the end of February 1916, fifty-seven courses were up and running and 2,400 students were enrolled. It was planned for 4,000 students to graduate a month but this turned out to be optimistic and problems placing trained students persisted in some areas. In some cases, it was because the factories were still being constructed and the workforce could not start. Some areas there was no munitions work. In others, lodging for newly arrived workers was expensive. The Ministry noted that some employers remained prejudicial. Some Institutes were capable of training skilled workers and were doing so. Some in the Ministry doubted if the factories could train enough skilled workers but nonetheless they urged the factories to try. In the meantime, the educational establishments would train the semi-skilled. There were those in government who thought that the project for using the training schools to provide new workers was pointless and would fail (HMSO, 1920). The factories, some still said, would do a better job of training. It would seem that no one could agree.

16 CONCLUSION

By 31 August 1916, 22,500 students received their training certificates of proficiency and 18,000 were placed in work (HMSO, 1920). March 1916 was counted as the high water mark for training

semi-skilled workers, a remarkably short space of time. After this, probably because they had proved their worth and convinced the Ministry of their effectiveness, increasing numbers of skilled workers were being trained by the Institutes. During the months of June, July and August 59% of the students graduating were women and a good number had been happy to move to another area to work. For example, the women taken from the fish industry in Aberdeen who trained at Robert Gordon's College and who transferred to the West Midlands to work in the munitions industry. Testimony came into the Ministry from all quarters praising the women trained by the Technical Institutes. As they fed into the workplace from the Institutes women began to prove their worth in manufacturing engineering. As time progressed they took more responsibility on the shop floor and some went on to train in skilled roles. Such was their impact and ability the Ministry encouraged their employment in the manufacture of shells and aircraft. In fact, in manufacture of the latter, their employment was demanded. September 1916 saw an important change and an important departure; officially, the notion of the Instructional Factories was born. The Ministry acquired a number of factories and Institutes, Loughborough (expanding all of the time) being one, under powers conferred by legislation Schofield, who remained in charge at Loughborough, was delighted and new courses were set up to teach skilled work. More money was sanctioned for more buildings, machines and staff and, because of the size of the new training facilities, more students could be trained. Being trained by quality staff on up-to-date machinery in a training factory, the qualified students were of high ability and the prejudices of employers and unions began to fade.

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ACHIEVING WORKPLACE INCLUSIVENESS BY USING ERGONOMICS RISK ASSESSMENT

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ABSTRACT

Traditional manufacturing work practices do not consider human variability issues during the design process. However, most manual assembly activities demand high levels of repetition and speed without compromising product quality and work productivity. Individual factors including age, gender, skill, experience and anthropometry cause variations in task strategies that lead to variations in individual and organizational work performance. The ergonomics-based risk assessment methods OWAS, REBA and RULA have been used to evaluate risk levels associated with working methods. This paper discusses the need for these methods to understand and highlight the key issues generated by these variations with the objective of minimizing these variations. Methods that can be used to promote working strategies that minimize the level of risk are described. The proposed research method potentially reduces work-related musculoskeletal disorders, injuries, pain, and promotes safe, healthy, productive and more inclusive working strategies suitable for a diverse working population.

Keywords: Ergonomics Risk Assessment, Human Variability, Inclusive Design.

1 INTRODUCTION

Humans are different in many ways. These differences influence human behaviours at work that eventually result in variations in working strategies. These variations might be because of differences in age, level of skill, background, experience, gender and lifestyle, and affect task performing strategies and working procedures. Many differences might be due to variations in the task performing capabilities that directly affect working strategies and procedures. This paper highlights the need to understand these variations, their causes and potential impacts on work performance. A special focus is placed on using ergonomics risk assessment methods for exploring the effects of human variations on workplace safety and productivity, and how these variations can be minimized so that more inclusive, safe and productive work practices can be promoted.

2 INDIVIDUAL FACTORS AND RISK EXPOSURE

The meanings of individual factors can be interpreted differently. However, the National Research Council and the Institute of Medicine (NRC/IOM 2001) stated that these are the factors that affect individual or personal responses to workplace exposure and can be thought of as physiological and psychological attributes. Individual factors like age, gender, level of skill, education, cultural background and nationality play a vital role in the selection of different working strategies for similar kinds of tasks, where these differences lead to varying levels of risk. For example, Punnett and Herbert (2000) found a relationship between work-related musculoskeletal disorders and gender, and that upper extremity disorders are more significant in women as compared with men. Usually, tasks with repetitive movements, lower physical demands and higher work pace are assigned to women. It is important to note that in the UK nearly 0.6M workers had accidents at work in 2010/11, and this resulted approximately two million lost working days (H.S.E. 2011). The National Research Council

and Institute of Medicine (2001) concluded that work-related musculoskeletal disorders of low back and upper extremities are the most costly health problem faced by workers and put a huge economic burden on organizations, in the form of lost wages, compensation costs and lost productivity.

Many psychosocial factors like job dissatisfaction, high job stress, inadequate work support, high mental pressure, perception of insufficient safety climate and lack of job control are also associated with work-related musculoskeletal disorders (Sobeih et al. 2008, Simon et al. 2008, Hofmann and Mark 2006, Stone et al. 2007). Similarly, age is also considered a contributing factor to work-related musculoskeletal disorders. Although older workers are more likely to work on jobs with low workload and lower physical demands, head-neck-shoulder symptoms still occur more frequently in older workers (Landau et al. 2008). Ilmarinen (2002) further mentioned that prevalence of musculoskeletal disorders between the age of 51 and 62 may increase up to 15% and this can have more serious implications for those who are exposed to repetitive and physically demanding work. In spite of the fact that physical work capacity of older workers decreases with age, still a significant proportion of older workers (aged 45 or more) are exposed to handling of heavy loads along with harmful working postures (Paoli 1997).

Differences in working techniques and procedures also play a key role in exposing workers to risk factors. Different workers perform their work in different ways, especially if they have an option to adopt a method of their own choice. Variations in working techniques lead to the adoption of different body postures, and these differences are more prominent in women as compared with men. Moreover, women are exposed to risk factors more frequently as the working methods adopted by them are more stressful. For example, they adopt strategies that acquire the use of hands at or above shoulder level and this is considered as a risk factor for neck and shoulder disorders (Keyserling et al. 2010, Dahlberg et al. 2004). Type of work is also an important factor to consider. For example, workers using Visual Display Units during work are exposed differently to risk factors because of the variations in their working techniques. Workers with poor techniques face the higher level of risk exposure in the forearm, shoulder and wrist (Karlqvist et al. 1998, Palmerud et al. 2012). Similarly, the importance of work style in terms of the level of risk exposure when using computers due to variations in working style and it has been concluded that wrist postures, speed of movements and applied forces while keying are the main variables in work style (Feuerstein et al. 1997; Haufler et al. 2000).

There are other individual factors like personality, past history, social issues and anthropometry, that might have a significant effect on performance at work. Factors such as physical, physiological and cognitive capabilities that are linked with age, culture and background also have a strong relationship with work performance of individuals. Unlike younger workers, the physical capabilities of older workers are lower and working strategies adopted by older workers might be significantly different because of this decline. Similarly, reaction time increases with age and this might be of great importance for those tasks where quick, accurate and simultaneous movements are required. It can be said that a number of individual factors like age, gender, skill, experience along with physical, physiological and cognitive capabilities play highly important roles in determining workplace safety and organizational productivity. Because of these individual factors, workers respond differently in the same situation. Existence of these human variability issues has been mentioned in the literature but very little has been proposed about how to solve these issues.

The next section describes the usefulness of ergonomics risk assessment methods for addressing workplace safety issues and how these methods have been used in highlighting risk factors and avoiding bad practices along with the promotion of safe and productive working techniques.

3 ERGONOMIC RISK ASSESSMENT

As concluded in the previous section, individual factors significantly affect working behaviours of workers, and variations caused due to these factors influence the level of risk exposure attached with any adopted working strategy. Work-related musculoskeletal disorders constitute an important occupational problem that has serious economic and social implications for individuals, organizations and society. It is extremely important to prevent these disorders by exploring major factors involved and by defining such strategies and methods that might assure safe and productive workplaces.

The assessment of discomfort and postural stress caused by different body postures is divided into two main techniques, known as observational and instrument based techniques. In the observational techniques, observers assess the angular deviation of a body segment from its neutral position. In the instrument based techniques a device is attached to the body and a continuous recording is carried out. Observational techniques are more commonly used in industry because of their low cost, ease of use and lack of interference with the job (Genaidy et al. 1994). OWAS, RULA and REBA are widely used in a variety of applications in different workplace conditions. As these techniques have been developed for different purposes, each technique has its own postural classification scheme which differs from the others (Kilbom 1994). Usefulness of these techniques has been discussed in several occupational settings. This paper describes the postural classification schemes and the effective use of OWAS and REBA for multiple applications.

The OWAS method (Ovako Working Posture Analysis System) describes a working posture by capturing and defining positions of three body parts; the back, arms, legs. The load handled (force applied) is also assessed and the three body part postures are further classified into different categories. Postures of the back are classified into four further categories, arms into three, legs into seven and three for force applied. In this way, 252 (4 x 3 x 7 x 3) posture and load combinations are presented in the form of four digit codes. These codes define the level of risk attached with any adopted posture and then the level of action category is defined. Posture combinations with higher risk of musculoskeletal disorders belong to higher action categories.

Table 1: The OWAS action categories (Karhu et al. 1977, 1981 and Karwowski and Marras 2003)

Action Category	Explanation
1	Normal and natural posture with no harmful effect on the musculoskeletal system - No action required
2	Posture with some harmful effect on the musculoskeletal system – Corrective actions required in the near future
3	Postures have a harmful effect on the musculoskeletal system – Corrective actions should be done as soon as possible
4	The load caused by these postures has a very harmful effect on the musculoskeletal system – Corrective actions for improvement required immediately

The usefulness of the OWAS postural assessment technique has been validated in several occupational settings, including construction, automotive, agriculture, nursing and the poultry industry. This method is able to detect the level of discomfort and risk involved in any working strategy and provides suitable recommendations for the improvement of working strategy and workplace design to minimize or prevent work-related musculoskeletal disorders (Karhu et al. 1977, Mattila et al. 1993, Nevala-Puranen 1995).

Like OWAS, REBA (Rapid Entire Body Assessment) is also a postural assessment system to assess the severity of musculoskeletal risk involved in working postures. Postural classification is based on scores for upper arms, lower arms, wrist, trunk, neck and legs; along with the external forces/loads applied, muscular activity caused by static and dynamic, rapidly changing or unstable postures and coupling effects. As a result of REBA scores shown in Table 2, five levels of action are recommended keeping in view the level of risk involved with postures. Action level 4 has a very high level of risk and action is necessary immediately whereas action level 0 has negligible or no risk (Table 2). The usefulness of the REBA method has also been described in the literature (Hignett and McAtamney 2000, Janowitz et al. 2006).

From the above discussion, it can be said that observational techniques are useful in assessing postural loads for a wide range of occupational settings. Furthermore, a detailed overview of results also provides an opportunity to highlight major causes of risks attached with any specific occupational setting. This study focuses on exploring the effect of the level of skill and experience attached on musculoskeletal disorders based on the differences in working strategies. The next section describes a

method in detail where these observational risk assessment techniques can be used to address human variability issues caused due to the varying level of skill and experience.

Table 2: REBA action levels

Action level	REBA score	Risk level	Action (including further assessment)
0	1	Negligible	None necessary
1	2-3	Low	May be necessary
2	4-7	Medium	Necessary
3	8-10	High	Necessary soon
4	11-15	Very high	Necessary now

ACHIEVING WORKPLACE INCLUSIVENESS: A PROPOSED METHOD

As discussed earlier, individual factors influence work performance as they are linked with human variations and these variations further lead to a varying level of exposure to risk factors at work. Ergonomics risk assessment methods have been found useful in highlighting the underlying causes of risks involved at work. This article proposes a systematic method of investigating human variations, their relationship with the level of risk attached, finding major causes and then achieving such inclusive working strategies that are healthy, safe, productive and equally acceptable for workers, in spite of their existing differences. For this study, workers with different levels of skills have been selected to explore whether or not the level of skill affects human work performance in terms of productivity and the level of risk involved at work, because of the differences in working strategies caused due to varying level of skill and experience.

After selecting appropriate tasks and workers the next step is to observe the differences in working strategies, which can be recorded using simple video recording methods. Different workers of varying levels of skill can be captured while working on different workstations performing similar kinds of activities. Here in this study, specialized, multi-skilled and semi-skilled workers (3 in each category) have been recorded on four different workstations on a sofa assembly line at a furniture manufacturing company. Data collection was carried out by simple video recording methods, where workers were recorded on each workstation at least 4 times while performing the same activity, so that workers attitude towards their work in terms of differences in working strategies can be observed and captured in detail. These differences can be quantified through the above mentioned ergonomics risk assessment techniques, like OWAS and REBA methods. This analysis can provide a detailed analysis about the differences in working strategies and their potential impact on workplace safety by quantifying the severity of the risk factors associated with different working strategies. In this way a comprehensive analysis can be carried out provides information about different things; for example, how skill influences working methods in terms of postural comfort, what are the most significant body movements that are responsible for risk at work, and which strategy is the best one in terms of productivity and safety.

All this information will lead towards evidence-based conclusions and recommendations can be developed for the promotion of more inclusive, friendly, safe and productive working strategies that can assure minimal effects from human variations. Furthermore, acquired results can be used for the training of relatively less skilled workers so that they can proactively develop their skills based on the optimal working methods.

4 THE WAY FORWARD: FUTURE RESEARCH

Future research will be carried out by the systematic and step-by-step implementation of the above mentioned research method. For this purpose, a case study at a furniture manufacturing industry is ongoing, where data collection through video recordings have been carried out. Workers with varying levels of skill and experience were recorded carrying out similar activities, so that the effects of skill and experience on task-performing strategies can be observed and analysed. The initial findings clearly show that skill and experience have a significant influence on working strategies. It has been found that object handling strategies are greatly affected by the level of skill, and this directly affects the productivity of workers in terms of effective time utilization. Moreover, the way an object is handled (a sofa in this case) influences body postures. Figure 1 shows two different workers handling

the object in different ways, where orientation of the object and adopted postures are the main causes of this difference. Further research will focus on the quantification of the level of risk attached to any strategy by using OWAS and REBA methods and this will be achieved by taking snap shots from the recorded videos and comparing the results for different workers. This will provide an opportunity to find major causes of risk at work and how these can be removed by providing appropriate training for the workers. Further to this, capturing different workers performing the same activity in different ways, also provides an opportunity to select the optimal and risk free working strategy from a larger pool of options.



Figure 1: Different object handling strategies of two different workers at the same workstation

5 CONCLUSIONS

Individual factors influence work performing strategies that have a direct relationship with risk factors that cause musculoskeletal disorders and injuries at work. Ergonomics risk assessment methods can be used to address human variability issues by exploring the risk factors influenced by these individual factors. Workplace inclusiveness can be achieved by promoting such working strategies that are easier to learn, more safe and equally productive for all workers in spite of their existing differences. The proposed method, which is based on observational ergonomic risk assessment techniques, can be used to quantify the level of risk attached to any working method. Future research will focus on further exploring the underlying effects of individual factors on the level of risk and work productivity, and developing guideline methodologies that might be used to minimize the influence of individual factors. Research findings can be used to develop and implement training procedures so that the variations at work can be minimized.

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HUMAN CENTRED MANUFACTURING: METHODOLOGY FOR ERGONOMIC PREVISIONAL EVALUATION OF MANUAL ASSEMBLY OPERATIONS

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ABSTRACT

The challenge of flexibility and productivity for manufacturing operations needs a new concept based on “human-centered manufacturing process”. This concept must consider basically the ergonomics of workplaces and workload balancing. The application of this concept is achievable through the detailed knowledge of the interaction between human and workplace, in particular as far as the mechanical load (or work load) arising from product design and from manufacturing process definition (included tools and equipment). The measurement of workload then is a fundamental for new (and existing) workplaces. In this paper is described the methodology that considers the procedure and instruments for measuring ergonomic parameters and the use of EAWS method to assess the ergonomic risk level of the workplace summarized by a score. EAWS considers postural aspects and dynamics of work activity. Design or modification of the workplace can be defined on base of the results obtained by the methodology application.

Keywords: Manufacturing, Ergonomics, Human-Machine Interaction.

1 INTRODUCTION

The robotic and the automation aren't able to solve problem of flexibility especially for a market that is characterized by a big number of niche volumes and a strong differentiation of the products inside the volume (mix of product). Manual work is a further and renewed possibility to face the problem.

The concept is to adapt the workstation to the work load acceptable for workers. It's possible to do this by the use of EAWS (Ergonomic Assessment Work-Sheet) method. The method allows the ergonomic assessment of workplaces through a risk index already in design phase. This method (based on standard ISO 11228), applicable for ergonomic analysis of the workplace and for work distribution, requires a quantitative measure of several ergonomic parameters. Effectively, the EAWS method requires quantitative inputs like forces and postures, etc., for it to be correctly applied. The methodology of measurement and analysis of the ergonomic parameters is then an important part of the new concept. The objective is to better verify the ergonomics of the existing workplaces but also to use this data to carry out the design of manual manufacturing processes.

Through this methodology of measurement it is possible to know the interaction between the man and tools and to adapt the functionalities of the workplace to the capacities of a group of workers (Christmansonn 2000). The evaluation of mechanical load requested by the workplace (considering

product and process together), is carried out in the working zone by the measurement of specific physical parameters necessary to perform the work activity. The measured parameters are then correlated with the anthropometry of workers, as well as with the method of work, the content of work (in terms of kind of operations requested for achieving a defined result) and the complexity of the work (in terms of precision and expected quality). Through a detailed and scientific measurement of several biomechanical parameters is possible also to carry out the mapping of the requested workload and its distribution among workstations in a typical assembly line of automotive production system.

Information, data and knowledge about measurement are used to build fields of ergonomics database, and are also translated in an operative procedure for supporting the design and the development of advanced workplaces.

After some years of development and experimentation today is possible to adapt the biomechanical workload assigned to a workplace according to an expected “performance profile”, in order to improve productivity and flexibility but also for increasing safety, ergonomics and wellbeing on the workplace.

2 METHODOLOGY DESCRIPTION

The methodology, finalised to the design of a new workstation for manual assembly operation, consists of six fundamental steps as follows:

1. *Workplace set-up*: is the first step necessary for the definition of the work activity (task and work method) and the work station configuration;
2. *Simulation*: is focused on work activity evaluation and can require a development of a mock up for physical evaluation;
3. *Measurement*: is the application of procedure for measurement and evaluation of ergonomic parameters and elaboration of gathered information;
4. *Risk analysis*: consists of calculation of the ergonomic level of the workplace through the use of EAWS method
5. *Modification*: is the phase of changing of the workplace set-up according to the indication from the step 4;
6. *Workplace validation*: is the verification of the modifications carried out and reporting.

2.1 Workplace set-up

The set-up of the workplace includes the definition (as designing hypothesis) of the geometry of the structure on which will be carried out the work, the lay out of the workstation and the work method (definition of tools and equipment included) to be used for the assembly operations. This step is useful for postures definition (according to the anthropometry selected for the workplace design) and for the work content definition.

2.2 Simulation

The simulation of the work activity is a step useful for visualization of postures and movement. It can be done by physical simulation by the use of a mock-up of the workplace or by the use of a virtual manikin like Jack, or equivalent tools. In the case of the building of a mock-up, the “mixed reality” can be used. The simulation (and the mock-up) enables the ergonomic parameters measurement in a laboratory context. The mock-up is concerning to the workplaces layout but also to tools and equipment.

2.3 Measurement

The step is focused on gathering information and data by the use of instruments for physical parameters detection like forces, pressure on the skin and angles related to postures. Measurements require a right calibration of sensors and their software, the evaluation of the technicality to allocate the sensors in order to collect the necessary information and not “dirty” information due to the manipulation of the sensors. The positioning of sensors between hand and tool or components to be

manipulated is very important and needs to be evaluated also through a set of tests in laboratory environment before the experimentation on the mock-up (it can be adopted also for measurement on field) of the workplace. Another aspect to be considered is the variability among different people (anthropometry, force level exerted) and behaviours during the application of force or type of actions adopted for a task. The study of the "work method" before starting the measurement is very important to understand how to measure the phenomena we are analysing, and to decide how to set sensors. The whole procedure of measurement shown in figure 1 is fundamental to get information affordable and useful for ergonomic design; (Di Pardo *et al.* 2012).

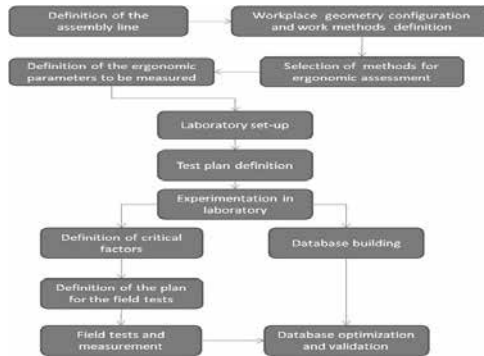


Figure 1: The procedure for measurement of ergonomic parameters.

2.4 Risk analysis

The risk analysis for whole body is carried out by the use of EAWS method. In this method there are 4 sections used for the ergonomic evaluation. Sections are: 1) postures of whole body, 2) actions with forces, 3) manual material handling, 4) movement of low load at high frequency. This method allows giving a score in function of several parameters. The risk index is based on a score with threshold values that make referring to the traffic light code (0-25 green, 26-50, yellow, >50 red). In this methodology the EAWS method is used to compare different solutions, from the first evaluation to the final optimisation. The advantage of such method is also due to the sections previously mentioned on which is possible to identify easily which factor is responsible of a high score of the risk index. Furthermore a modification can be evaluated only by changing of parameters of the section involved in the optimization.

2.5 Modification

After the first set-up of the workplace, a first analysis by EWAS method is carried out. If the evaluation is green, no modifications are necessary. If yellow or red evaluations, a modification of the workplace (or the mock-up) is necessary. Modification can involve the lay-out of the workplace, the tools used, the work method and finally, even the product.

2.6 Workplace validation

After the analysis of ergonomic parameters step by step, it is also important the valuation of the improvement gained from the first approach to the last optimisation. To do that is useful to use the following ratio of risk index $R = (I_f - I_i)/I_i$, where I_i is the score of the first hypothesis (I initial) and I_f is the score after the last modification (I final). This ratio gives us the dimension of the improvement. The validation is carried out by a group of expert people who can judge the quality of the set-up defined after the complete design phase.

3 THE CASE STUDY

The methodology described in the above paragraph was applied to the case study: “new plastic bushes for holes sealing of a car door panel”. Two innovative bushes were evaluated: the pink version and the yellow version (figure2). Differences between the two versions are only the wing fastener along the body of the bush (shorter and continuous for the Yellow version; longer and cut near the bush’s head for the Pink version).

The objectives were the evaluation of the forces exerted during the assembly of new bushes and the evaluation of tool handling in order to select the best solution or to suggest the improvement for the tool and/or the work method.

The *setup of workplace* was made by referring to a typical assembly operation carried out in the final assembly line of a car industry. Posture and tools adopted during work activity were evaluated.



Figure 2: The new plastic bushes (P-pink & Y-yellow) with gasket and water sealing.

The *Simulation* of the work activity, on the mock-up of the workplace, was carried out at the ERGOLAB of Fiat Group Automobile (FGA) and some samples of the plastic bushes were developed by supplier in agreement with the department of product engineering of FGA. The test was carried out by seven repetition of measurement for each configuration and by the use of three different operators.

The *Measurement*, including the set-up of the procedure, the instruments calibration and the study of the work method for sensors positioning, was done at CRF (Laboratory for Ergonomics of Factory). The instruments used for this evaluation were electro-goniometers for the posture detection and two piezoresistive sensors for pressure/force detection (figure 3):

- the “FlexiForce® sensors” measure finger pressure and force using a small sensing area (9.53 mm of diameter) with a good linearity error (<3%). It is very flexible (0,2 mm of thickness).
- the “Grip™ system” measures static and dynamic pressures in the grasping of objects and it is mainly used for the tool handling evaluation. It is made of a thin, high-resolution pressure sensor with a sampling rate up to 500 Hz. The sensor has eighteen sensing regions that can be individually positioned over important anatomic sections of fingers and palm. Sensor is covered by a cotton glove usually used in production plant.



Figure 3: The force sensors used; Gryp system (and the glove with sensors) and the Flexiforce

The *Risk analysis* was carried out considering the posture depending from the lay out of the workplace of the assembly line and the possible tool modifications. The calculation of the risk index was made by using EAWS method. The type of grasp and the tool handgrip were also considered.

The *Modification* was carried out on the handgrip of the tool used for inserting the bush. In the figure 4, S_1 , S_2 and S_3 on the tool handgrip are the contact surfaces between the hand and the handgrip itself (Types 1, 2 and 3). Specific pressure on the skin is then depending on the contact surface area. The bushes modification was already defined with the product designers.

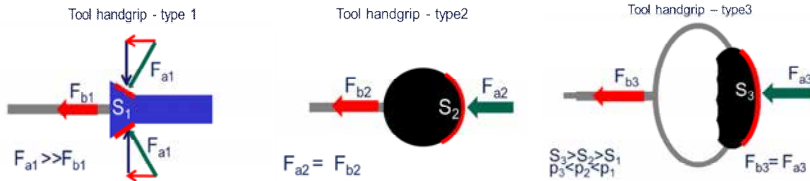


Figure 4: Tool handgrip of three different solutions evaluated

The *workplace validation* was defined according to the index ratio described before. In this case the posture of the whole body does not change and has no influences on the calculation. Forces exerted are depending on the version of the bush used. Types of grasp, as well as the specific pressure on the hand, are depending on the shape of the tool's handgrip. An interview to the operator at the end of the testing phase was also carried out.

4 RESULTS

The two bushes evaluated require different effort for their insertion and give also different feedback in tactile perception. The wing fastener of the pink version allows perceiving a "click" when the insertion is completed. The yellow version doesn't give feedback. As visible from the diagram in the figure 5 (got directly by the sensor during the measuring of the insertion), there are two instants in which the force decreases (zones 1 and 2). The first decrease (zone 1) is after the force necessary to achieve the assembly ($F_{insertion}$) of the bush. It's perceived by a click that means the achievement of the locking of the bush. The second decreasing (zone 2 in figure5) is after the maximum force (F_{max}) exerted by the worker before to stop his action at the end of the task. If there isn't the perception of the click (as for the yellow version of the bush), the worker, to be sure of the locking of the bush, pushes with a higher force (F_{max}) with respect to the insertion with feedback.

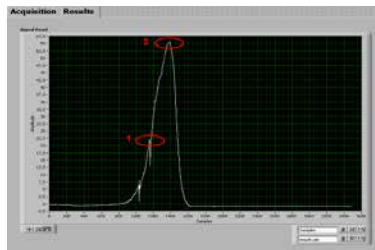


Figure 5: Force measured by the sensor during the insertion of a fastener

This can be also seen by the two level of the force described (F_{max} and $F_{insertion}$) in the figure 6. On the left side of the figure 6 there is the table of references of forces used in the EAWS method.

The results in terms of forces measured by the sensors are reported on right side of figure 6 and two aspects have to be highlighted. The first aspect concerns the upper diagram in which the force is exerted by the finger (for the two kinds of bushes) and the second aspect concerns the lower diagram where the force is exerted by the use of three different tools (types 1, 2 and 3). In both cases forces have to be compared with the forces of the EAWS table, according to the type of grasping used

(finger or "power grip" for the tool). No influence of the force is due to the gasket/sealing for the P-bush.

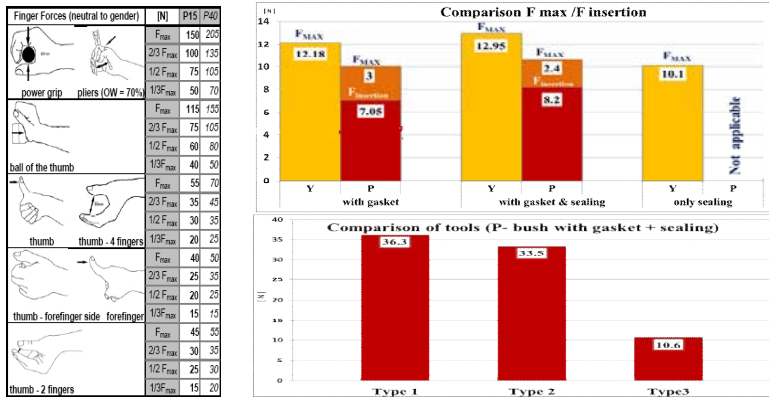


Figure 6: Table of EAWS method for force references and measured forces in mounting of bushes (Y= yellow, P= pink).

Because the evaluation is carried out to define a new possible solution (design) the column (on the EAWS table) to which make reference is the P15 (15 percentile) because more protective for workers. Considering these results in relationship to the different shapes of the handgrip of the tools, the following consideration can be done. The forces exerted with and without sealing are higher for the yellow version, so the better solution is the pink one. If we consider the best solution as far as the geometry of the bush, the use of a tool is recommended. Same force exerted with finger or with tool, leads to a comparison with different value of the force on the EAWS table. The calculation of the "R" ratio shows a significant reduction (about 20%) of risk index, if the handgrip type 3 is selected in respect to the type 1. (Both solutions were in the green area of the risk index). The handgrip type 3 of the tool is better than the type 2 and 1 because allows a good grasp and because the local pressure on the hand is lower.

5 CONCLUSION

The work carried out on a simple component can put in evidence the possibility to use objective methodology of analysis for the design phase based on measurement of ergonomic parameters. The design phase concerns the development (or the selection among different possibilities) of components (bushes in this case), as well as the design of an optimized tool for assembly of components. The same approach can be used in the case of the work-method design or in the case of the workplace layout design (in which postures of whole body are mainly involved). The EAWS method, because based on quantitative evaluation of ergonomic parameters (like forces), is a powerful method for design and set-up of workplaces. The methodology described above for measurement of forces as well as postures is another very effective way to proceed in the design phase definition.

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AUTOMATING HUMAN SKILLS : PRELIMINARY DEVELOPMENT OF A HUMAN FACTORS METHODOLOGY TO CAPTURE TACIT COGNITIVE SKILLS

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ABSTRACT

Despite technological advances in intelligent automation, it remains difficult for engineers to discern which manual tasks, or task components, would be most suitable for transfer to automated alternatives. This research aimed to develop an accurate methodology for the measurement of both observable and unobservable physical and cognitive activities used in manual tasks for the capture of tacit skill. Experienced operators were observed and interviewed in detail, following which, hierarchical task analysis and task decomposition methods were used to systematically explore and classify the qualitative data. Results showed that a task analysis / decomposition methodology identified different types of skill (e.g. procedural or declarative) and knowledge (explicit or tacit) indicating this methodology could be used for further human skill capture studies. The benefit of this research will be to provide a methodology to capture human skill so that complex manual tasks can be more efficiently transferred into automated processes.

Keywords: skill acquisition, task analysis, automation.

1 INTRODUCTION

Most modern high-value manufacturing systems continue to rely heavily on manual work processes. Technological advances have increased the possibilities of developing intelligent automation to replace manual tasks which could improve operational efficiency, productivity and working conditions within an organisation. Currently, however, there is insufficient knowledge and understanding of what manual tasks, or task components, would be most suitable for transfer to automated alternatives. Capturing simple and observable physical task activities is relatively straightforward, for example by objective measures of motion. However, more complex manual tasks often involve a significant amount of unobservable cognitive processing that cannot be captured as readily. Thus, if intelligent automation alternatives are to be developed to replace human work, it is necessary to be able to classify the more complex and concealed aspects of human skill – the cognitive processes responsible for the output of physical activity.

1.1 Hierarchical Task Analysis (HTA)

Hierarchical task analysis (HTA) has been recognised as one of the most commonly used and versatile methods for deconstructing and analysing manual activity and has been used to represent a wide range of tasks (Kirwan and Ainsworth 1992), including those with cognitive components. An HTA

approach represents a systematic method of describing how work is organised in order to meet the overall task objective. It involves a top-down approach that breaks down a task into a nested hierarchy of goals, sub goals, operations and plans. The operations are the observable actions which need to be performed by an operator (at the lowest level of the HTA). Plans are inserted between the levels of the hierarchy and represent the unobservable decisions of an operator, determining the sequences in which the operations are performed.

There have been concerns over the ability of HTA to fully express cognitive task elements (Stanton, Salmon, Walker, Baber and Jenkins 2005) and subsequent attempts to identify a single analytical method that can adequately assess both types of behaviour, have largely been unsuccessful. Consequently, a number of authors (for example, Phipps, Meakin and Beatty 2011) have proposed extensions to the standard HTA that would incorporate cognitive task components, examples of which will now be discussed.

1.2 Extending HTA: Task Decomposition and Skill Classification

Task Decomposition provides one approach for expanding the HTA method in order to elicit more detailed task information, including the cognitive aspects of task performance. During a Task Decomposition, the lowest levels of an HTA (the operations) are broken down further into a number of categories which are most relevant to the research requirements (Kirwan and Ainsworth 1992). The Task Decomposition technique may be used to apply skill classifications to the HTA and identify task components associated with 'tacit knowledge'.

Tacit knowledge refers to the sort of information that people use readily but find difficult to express because it is not consciously recalled, it is applied instinctively and often resembles intuition (Smith 2001). Unlike explicit or codified knowledge, which can be more readily communicated (verbally or in written formats such as in operating instructions and reference manuals), tacit knowledge is typically experiential, learnt by observation, imitation and practice, or by being socialised into a way of doing things. Consequently, it is difficult to convert tacit knowledge into explicit knowledge as it requires 'finding a way to express the inexpressible' (Smith 2001).

Phipps et al. (2011) investigated the use of the Skill, Rule and Knowledge based (SRK) framework developed by Rasmussen (1983) as a means for expanding HTA to identify tacit cognitive task elements. According to the SRK framework, human performance during a task can be classified using one or more of three 'levels': i) skill based (associated with routine, learned actions); ii) rule based (associated with rule- or heuristic-driven responses to problems) and iii) knowledge based (associated with reasoning about problems for which there is no obvious response). Each of these levels involves progressively more cognitive effort, with the skill based level associated with tacit knowledge and the knowledge based level associated with declarative (explicit) knowledge.

The aim of this research was to trial an appropriate methodology for the capture of tacit skill to enable the measurement of both observable and unobservable physical and cognitive activities associated with manual tasks. In light of the proposed techniques outlined above, the methodology to be trialled would involve HTA and Task Decomposition.

2 METHOD

The study was designed to test a methodology for capturing tacit skills by exploring the cognitive elements involved in the performance of a manual task. For this, a combined HTA and Task Decomposition approach was selected as this would enable progressive exploration of a suitable manual task using subject matter experts (SMEs).

2.1 Task

To test the methodology, a relatively simple manual task involving tacit and explicit skill was required. A tungsten inert gas (TIG) welding task of approximately 5-10 minutes was selected: this was simple enough to minimise unnecessary complexity from the task itself but would still involve a considerable degree of cognitive processing for the co-ordination of continuous and simultaneous physical activities (the use of both hands for the weld and one foot to operate the gas release foot

pedal). The task was ideal as it offered a relatively straightforward procedure with the need for tacit skills for continuous information processing and decision-making.

2.2 Participants

Two experienced welders (at least ten years of experience) took part as SMEs for the main data collection which required them to be observed while performing the manual task, describe their actions in recurrent interview sessions, and to instruct two novices. An independent expert welder was also recruited to assess the reliability and validity of the analysis. In addition, a further SME was recruited for informal discussion simply to provide a broader contextual understanding of the task.

2.3 Process

Prior to formal data collection, informal discussions were held with the two SMEs to plan the proposed data collection procedure and build rapport. This provided the researchers with an opportunity to gain a general understanding of the task to help inform subsequent questioning and the selection of task decomposition categories.

Four main data collection sessions lasting between 2.5 to 4.5 hours were conducted, two per SME at their own welding facilities. During the first sessions, the SMEs demonstrated the setting up and laying of several welds, providing detailed explanations of the activities and demonstrations, responding to questioning and providing basic welding theory. During the second sessions, each SME instructed a novice to set up and lay a weld so that the instruction could be observed and notes made on the procedure in order to build the HTA. Both expert welders chose to decompose the welding task into part tasks and then build the part tasks into a full task. Data collection and analysis was progressive and iterative, with emergent data and results being used to refine further data collection and the selection of the task decomposition categories. Observation sessions were run until redundancy was achieved (i.e. until it was evident that no further or new insights were emerging) and full coverage of the task under investigation was achieved.

2.4 Analysis

The progressive re-description of the sub-goal hierarchy could theoretically continue indefinitely and understanding when to stop the analysis can be one of the most difficult aspects of HTA. Stanton et al. (2005) recommended that the analysis should continue until the sub-goals and operations are clear to both the analyst and the subject matter expert(s). This method was used in the current study and the procedure for developing the HTA has been presented in Figure 1.

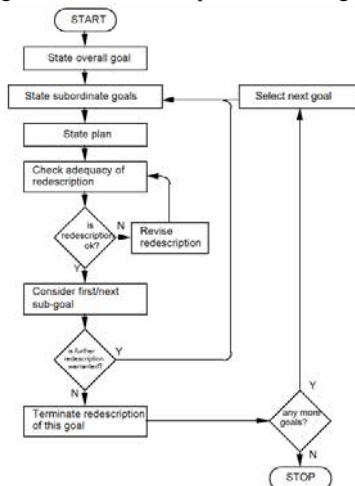


Figure 1: Procedure for developing sub-goal hierarchy (Stanton et al. 2005).

In deciding on the task decomposition categories, reference was made to the categories suggested by Kirwan and Ainsworth (1992) as well as taking into consideration the preceding literature on the nature of human skill, skill acquisition and human error. The HTA and Task Decomposition analysis were reviewed firstly, by one of the welding experts that had taken part in the study and, secondly by an independent subject matter expert.

3 RESULTS AND DISCUSSION

Both the HTA and Task Decomposition analysis were documented in tabular form. The HTA provided a systematic representation of how task processes should be organised in order to successfully complete the assigned task (Table 1). Each level of the HTA was represented in a numerical sequence; for example, the overall goal of 'Lay weld' which was numbered '4' to represent a super-ordinate goal. The immediate sub-goals were then numbered from 4.1 – 4.7, with operations represented in a similar manner (e.g. 4.4.1 – 4.4.2). In this way the HTA fully described the physical task components and provided a template from which further analysis could be performed using a Task Decomposition.

Table 1: Hierarchical Task Analysis for a manual task (a TIG welding example); sub-goals have partially been removed due to space restrictions.

0	Set up and lay a butt weld. <i>Plan 0: 1 - 2 - 3 - 4</i>	
1	Set up equipment. <i>Plan 1: 1.1 - 1.2 - 1.3</i>	
	1.1	Select filler rod
		
2	Simulate laying a weld. <i>Plan 2: 2.1 - 2.2 - 2.3 - 2.4 - 2.5 - 2.5 - 2.6 - 2.7</i>	
	2.1	Place (right or left) foot on foot pedal, and depress
		
3	Tacking together the welding pieces. <i>Plan 3: 3.1 - 3.2</i>	
	3.1	Prepare to tack the welding pieces. <i>Plan: 3.1.1 - 3.1.2 - 3.1.3</i>
		
4	Lay weld. <i>Plan 4: 4.1 - 4.2 - 4.3 then 4.4 - 4.5 - 4.6 in unison throughout the laying of the weld, then 4.7</i>	
	4.1	Position torch at the start of the weld
		
	4.4	Manipulate the filler rod. <i>Plan 4.4: 4.4.1 - 4.4.2 in unison through the laying of the weld</i>
	4.4.1	Stroke the filler rod in and out of the weld pool
	4.4.2	Feed the filler rod through the fingers
	4.5 *	Control the movement of the torch
		
5	Make post weld inspections: <i>Plan 5: 5.1 - 5.2 - 5.3 - 5.4</i>	
	5.1	Lay down tools, remove mask
		

* = sub-goal has been used to illustrate the task decomposition analysis in Table 2

Using an appropriate set of sub-headings / categories, each task process identified in the HTA was described in a series of statements concerning particular aspects of the task. The resulting Task Decomposition analysis has been presented in Table 2 (a partial decomposition of sub-goal 4.5 'Control of movement of torch' is shown for purposes of brevity).

The Task Decomposition showed that the sub-goals and operations described in the HTA could be further broken down according to the different purposes of each task component. The 'Purpose' category was therefore used to provide additional background information related to each component in order to improve the comprehension of the HTA and Task Decomposition analysis. Once the context of performance was established, the subsequent categories ('Cues and expectancies' and 'Decision') identified the system cues that were used by the operators to inform the decision-making process that ultimately lead to a physical 'Action / response' in order to achieve the intended purpose.

Within these categories, a range of cues (e.g. visual, tactile or auditory sensory information) were used by the operators to evaluate the characteristics of the system (e.g. 4.5(a): 'Visual – looking for weld pool to be in the correct plane') and to make inform decisions. The use of multi-sensory information to perform a single aspect of the task highlights the complexity of human performance.

However, by understanding the cues and decision strategies that initiate human performance, more relevant automation alternatives can be developed.

Table 2: Task Decomposition for a manual TIG welding example (restricted to sub-goal 4.5)

HTA Level	Task Decomposition Category									
	Purpose	Cues and expectancies	Decision	Action / response	Performance level	Co-ordination requirements	Critical values	Likely errors and consequences	Potential to correct errors	Different welding configurations
4.5 <i>Control of movement of the torch</i>	(a) For even heat dispersal	VISUAL: Looking for the weld pool to be in the correct plane.	Is the weld pool in the wrong plane?	Horizontal movement of torch. Ensure the heat is evenly distributed over the seam line.	<i>Skill based</i>	n/a	n/a	The arc is often not uniform. If the weld pool is in the incorrect plane = reduced penetration	n/a	n/a
	(b) To control torch speed	TACTILE: Feeling how tacky the weld pool is when the filler rod is dipped into it.	Is the weld pool too viscous?	i) Change speed of the torch. ii) Adjust foot pedal to control the current.	<i>Skill to Rule based</i> (depending on attention).	Co-ordinate weld speed with foot pedal control.	n/a	i) Moving the torch too slowly = heat build-up causing a hole. ii) Moving the torch too fast = reduced penetration	Adjust speed of movement or current.	n/a
	(c) To maintain optimal height above the weld pool	AUDITORY: Faint hiss.	Can you hear a faint hiss? Electrode too high from the parent metal.	Move the electrode to the correct height above the parent metal.	<i>Skill to Rule based</i> (depending on attention).	Co-ordinate the filler rod. Ensure tip of filler rod is within the gas envelope.	2 mm above parent metal.	If too high, the heat will reduce.	Move the electrode back towards the parent metal	Variation with different metals, thickness etc.

Additionally, the Task Decomposition enabled the performance of the operators to be classified according to the SRK framework (Rasmussen 1983). This 'Performance level' category identified task components in which the action / response of the operator was based on the use of tacit knowledge. The Task Decomposition found that operators predominantly used a Skill to Rule based level of performance which suggested tacit knowledge was mainly used to perform the overall task. None of the task components were classified as Knowledge based, although, this would be expected due to the high level of experience of each operator. In many situations, the distinction between Skill and Rule based performance levels was not clearly defined and task components often involved aspects of both classifications. Generally, the cues and decision-making strategies were found to be Skill based as these relied on subjective evaluations of sensory information obtained by the operators. Rule based aspects of the task components tended to be associated with the selection of appropriate actions / responses from a set of alternatives (e.g. sub-goal 4.5(b)) or where critical values were used to define the intended outcome of the action / response (e.g. sub-goal 4.5(c)).

Skill based task components (relied on tacit knowledge) were more difficult to fully represent than those which were predominantly Rule based and further investigation would be recommended to adequately understand these task components. Nonetheless, the classification of individual task components according to the use of knowledge has provided a useful framework in order to evaluate

the suitability of task components for transfer to automation. Although human performance tends to become less error prone with the acquisition of skill and expertise, errors still occur. Automated alternatives may offer improved reliability however, within the context of function allocation between humans and automated systems, it is pertinent to consider the potential for errors and the capacity for a situation to be recovered. Task components associated with a Rule based performance tended to demonstrate an ability to recover errors, which may indicate an improved suitability for transfer to automation. Task components that relied on mainly on Skill based performance however, showed limited potential to resolve errors as there was a greater reliance on tacit knowledge to control performance.

Limitations of this research are related to the small sample size of participants and the specific nature of the task. A larger sample size would enable the influence of individual differences to be assessed. To maximise the reliability and validity of the technique, it should be applied across a range of tasks to assess its applicability in different types of manual work. 'Different welding configurations' were considered within the Task Decomposition to slightly expand the scope of the manual task beyond the particular subject task. It was evident that the operators were not only experienced in a single, particular task but rather across a multiplicity of manual tasks. The Task Decomposition-HTA technique should also be trialled across different experience-level groups so that the effects of training and experiential learning pathway can be better understood.

4 CONCLUSIONS

A Task Decomposition was used to expand traditional Hierarchical Task Analysis to include exploration of tacit knowledge. This method enabled both the observable and unobservable physical and cognitive aspects of a manual task to be identified as well as specific task components that could be suitable for further investigation. Experienced operators were found to mainly use Skill to Rule based performance levels, from which the use of tacit knowledge was inferred. This is likely to be due to their high level of experience and the simplicity of the task. Future investigations should attempt to assess a wider range of experience levels (e.g. novice and apprentice operators) in order to understand the progression associated with training of experiential, acquired knowledge and how this develops instinctive or intuitive activities. Providing instruction to novices was beneficial to the development of the Task Decomposition as, experienced operators had to be more cognisant of what they do in order to verbalise it. This means that observations of training scenarios are likely to provide a head start in further development of the Task Decomposition-HTA technique. Individual differences between operators were observed in situations where they were able to choose between alternative strategies (e.g. sub-goal 4.5(b) in Table 2). These actions would likely be based on 'rules-of-thumb' developed by the operator through experience. The potential impact of individual differences between operators needs to be explored in further research to ensure validity of the Task Decomposition-HTA technique. Finally, as the purpose of developing this methodology is ultimately to evaluate what elements of manual tasks are most suitable for transfer to automation, future work must develop in this direction. When confidence in the reliability and validity of the method has progressed it will then be apt to test suitability for transfer to automation, of varying type and levels. This is the intended direction for this research theme.

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DIGITAL MANUFACTURING IN FIAT GROUP AUTOMOBILES: VIRTUAL SIMULATIONS FOR PRELIMINARY ERGONOMICS OPTIMIZATION OF WORKCELLS IN THE DESIGN PHASE OF A NEW CAR MODEL

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ABSTRACT

New standards on work organization in the automotive industry, require a new concept of design methods: the human centred process. In Fiat Group Automobiles (FGA) the “Digital Manufacturing” (DM) project has started with the goal to create simulation tools and methods to improve the design of new cars’ manufacturing processes giving a special attention to manual operations. The DM approach is based on a detailed “virtual plant” where virtual mannequins interact with digital models of car’s components, equipment, containers, etc. in order to simulate and improve working conditions with many benefits on ergonomics, safety, final product quality, work organization and general production costs. The key factor for this approach is that with DM methodologies, designers and engineers have, already in the design phase of a new car’s manufacturing process, a preliminary estimation of the numerical indices used in the plants to check if workcells are compliant to international standards and regional safety laws. In this way the most important ergonomic indices (like Niosh, Snook & Ciriello, EAWS, etc.) become a “design tool” that allow to change/improve project solutions (designing easy and comfortable work tasks, equipment, tools, etc.) and to distribute the work load in an optimal way between workers.

Keywords: Digital Manufacturing, Digital Human Models, Ergonomic indices.

1 INTRODUCTION

During the last years, the global car market has changed becoming more competitive and unstable due to several factors (legal, financial, environmental, etc.) so that the most important automotive OEM have been obliged to react to this scenario.

In terms of general corporate strategies, partner-ships and joint ventures have been established between different groups/brands to ensure: the presence in the emerging markets, a larger products offer in all market segments, the optimization of the support networks: suppliers, resellers, maintenance. In terms of the products offer, designers and engineers have tried to differentiate solutions in order to get closer to the demands of customers trying also to anticipate new trends and future market requests. The continuous request to produce different new models in few years oblige OEM to develop more flexible assembly lines and better methods for job planning on the same lines. In the meantime, safety norms and product quality reasons request to improve working condition also according to international standards. Therefore Ergonomics and work organization concepts have

received a very strong development and new organizational models have been created using ergonomics as a guideline to organize and optimize production in the plants. Very important examples in these area are World Class Manufacturing (WCM) for production theories and European Assembly Worksheet (EAWS) for ergonomics and work organization (Ergo-UAS).

However, the previous concepts allow to achieve the most important benefits only when they can be applied in the design phase of a new car's manufacturing process because, in this case, the whole production system can be changed and optimized. On the contrary, applications on already existing systems are less efficient or completely impossible due to technical reasons and to very high costs requested to change physical tools, equipment, etc.

For this reason, FGA has created the "Digital Manufacturing" project whose final goal, for manual operations, is to create simulation tool and methods that allow to apply ergonomics and work organization methods in the early phases of a new project development.

In order to show how to achieve this result, it important to remember that, generally speaking, ergonomic analyses aim to improve different aspects of the manual work: postures, forces, manual material handling, etc. They have a different complexity level and perimeter of interest, but all of them try to define optimal conditions in order to guarantee fast and comfortable work tasks according to specific numerical ergonomic indices (like the Niosh index for manual material handling) that can be applied on physical existing workstations.

The DM approach has been based on the process to adapt these ergonomics methods to the "virtual plant" environment in order to get, already in the design phase, an high correlation between results obtained by the virtual simulation with those obtained on the physical analysis of the work tasks. Thanks to this process, it becomes possible to use ergonomic indices as a "design tool" in order to change/improve project solutions and to distribute the work load in an optimal way between workers.

2 DIGITAL MANUFACTURING AND HUMAN MODELS

One of the most important aspects of the DM project, is the information's "active management" that allows designers and engineers to make detailed virtual simulations in order to improve the car's manufacturing process. This concept has requested an important development on the methods used by FGA Manufacturing Engineering to manage all the information related to the production process: technological data are available in an unique simulation environment that contains virtual models of the car components and of the production plant (robots, tools, equipment, etc.). Using this global data management system, product designers save the car models in a shared environment where process designers and suppliers can perform manufacturing simulations in a cooperative working environment using virtual tools working on a completely geometrically faithful representation of the future production plant.

The key factor to improve DM simulations has been to insert digital human models and "human centred" simulation methods in the virtual environment in order to perform certified simulations for all the manual operations that are designed for the production process in the future plant.

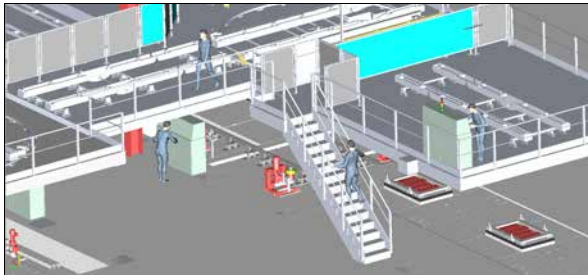


Figure 1: A virtual model of a production plant.

Digital Human Models are nowadays a standard in simulations software and many commercial products, like “Jack” by Siemens, are available on the market (Stephens, 2006). They give to designers all the most important facilities in order to perform manufacturing task simulations: different anthropometric and biomechanical models, visibility and reach-ability functions, direct and inverse kinematic algorithms, etc.

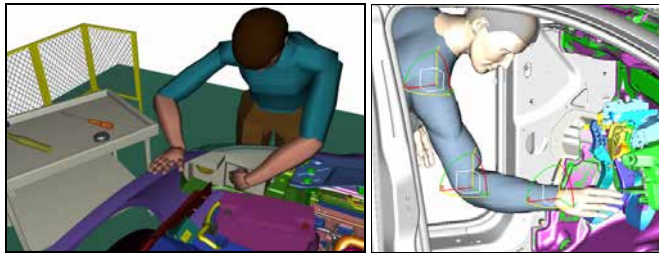


Figure 2: Virtual humans performing assembly tasks.

The fundamental development on which FGA has based the Digital Manufacturing project for human simulations, has been the effort to improve standard digital human modelling software (and the related simulation methods) in order to let them be compliant to FGA’s design standards (based on international technical norms - ISO/EN norms -) and FGA’s production standards that are based on European/Italian legal specifications on safety and ergonomics.

In this way, designers have not only a virtual representation of the future plant but also the virtual tools to validate design solutions. This is very important for ergonomic problems that are usually discovered in the early production moments when product/process changes on physical objects are extremely expensive and don’t bring to optimal solutions.

In order to achieve the above benefits, the first step has been to create virtual mannequins compliant to ISO anthropometric models (ISO 7250/1) and anthropometric measures (ISO 7250/2) for the different populations where FGA production plants are present. Starting from the basic functions to change mannequin’s dimensions, specific sets of virtual humans have been created according to the above measures. Besides, reference frames on these mannequins have been created in order to have specific points on which evaluate body angles, distances, etc. according to the most important ergonomics methods requested by ISO/EN standards (ISO 11226) and by FGA’s standards (like OCRA or EAWS).

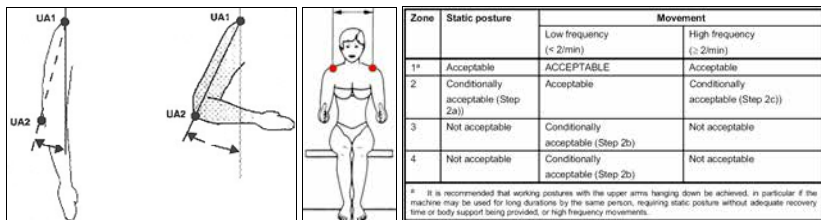


Figure 3: Reference points and body angles defined by ISO standards and reproduced on the virtual mannequins.

3 ERGONOMIC METHODS IN THE VIRTUAL ENVIRONMENT

Ergonomic analysis in a virtual environment have the final goal of reaching an ergonomic optimization of the workstation already in the preliminary phases of product process development. These analyses differ for complexity and for area of interest. The most basic checks are related to

accessibility and visibility tests of the working area/object. For these applications, standard anthropometric measures are very important because they are references that allow designers and engineers to give a final answer on a design solution acceptability. To achieve this result, mannequins dimensions should be close, as much as possible, to the working population that should have to perform the requested assembly task in the future plant.

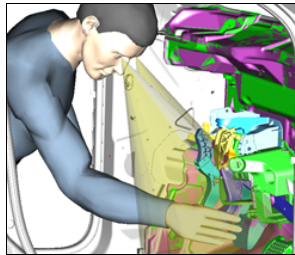


Figure 4: Visibility and reachability analyses.

Another kind of ergonomic analysis is related to the check of body postures assumed by workers during assembly task. These are very important because they allow to avoid musculo-skeletal disorders and safety problems. Many methods are available in the scientific literature to evaluate working postures but FGA references are: the international standard EN 1005/4, OCRA index and the EAWS method. All of them define a set of acceptable, critical and not acceptable body movements, position, angles.

Using the DM approach, designers and engineers use the advanced mannequins (those that are most close to the working population of the plant) to evaluate the above standards. To achieve this result, they place the virtual mannequins in the reference posture for the analysed assembly task. This posture can be determined also using virtual reality facilities or inverse kinematics algorithms that allow to forecast the most probable posture the worker can assume during his job (Di Pardo et al, 2008). Specific reference points are defined on the mannequins. These are directly related to the body movements and angles defined in the above ergonomic indices so engineers can immediately have a preliminary evaluation of the desired index. This operation is very important in the early design phases of the car manufacturing process because it also allows to define optimal values for the measures that strongly influence ergonomic conditions during the use of equipment, tools, etc. Even general production lines features could be results of these analyses (like, for example, the car's height along the assembly line).



Figure 5: Sticky 2D representation of a standard virtual mannequin and its postural evaluation according to EN 1005/4 standard.

Finally manual material handling (MMH) analyses are described for ergonomic optimization of virtual workstations. This methodology is applied, in FGA, to all those (manual) assembly task where safety risks for manual handling of loads (lifting, carrying) could be present.

In order to carry out an optimal simulation to analyse MMH critical issues, engineers use to create, in the virtual plant, one (or more) virtual humans in the most important postures related with

the actions / positions that determine critical moments of the MMH assembly task. For example, to simulate a manual lifting of an object, designers can save different postures of the virtual dummy during weights movements. These positions can seriously affect the analysis. In the same way, a correct positioning of the dummy's hands are very important and reference points on them are necessary in order to get results compliant with the ISO standards. With the support of the frames previously placed on the mannequin, it is possible to find the relevant measures for the evaluation of lifting index (NIOSH).

Here again, the lifting index is very important in the design phase because checking the results, it is possible to change equipment dimensions in order to improve ergonomic conditions for the worker.

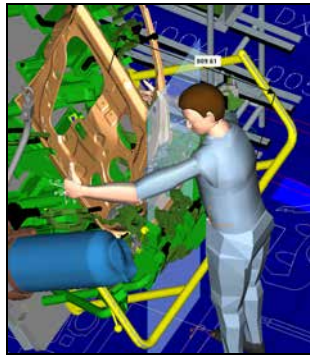


Figure 6: Critical measures for lifting operations according to Niosh index

4 CONCLUSIONS

In this paper, the authors have shown the approach used in Fiat Group Automobiles based on simulation methods and tools to analyse ergonomics aspects of future workcells inside the Digital Manufacturing Project. The focus has been given to human simulation so principles of Digital Human Modeling (DHM) have been used and implemented inside the simulation tools used in FGA.

The approach is based on a 3D human model that can be quickly used by project designers and plant ergonomics experts. Users input information about working task (dimensions, targets position, etc.) and the tool shows the expected working condition in terms of the most important ergonomics indices. To achieve this result, efforts have been done to deal with two key factors: anthropometric and human movement models. These topics have been improved in order to get them compliant with the international standards that FGA uses for project/process design and physical validation. Using these tools it becomes also possible to do a preliminary ergonomic analysis of the future workcell according to the most important ergonomics indexes (like OCRA and EAWS) in order to get a preliminary ergonomics optimization of workcells during the initial phases of a new product/process.

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APPLICATIONS AND BENEFITS OF DIGITAL HUMAN MODELS TO IMPROVE THE DESIGN OF WORKCELLS IN CAR'S MANUFACTURING PLANTS ACCORDING TO INTERNATIONAL STANDARDS

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ABSTRACT

During last years, the car's manufacturing process has deeply changed because of several factors affected the automotive global scenario. As a consequence, design methodologies of the plant's workcells have changed. In particular, ergonomics for manufacturing system has become a key factor to improve product's quality, safety and work organization. In this paper, the authors show the approach used in Fiat Group Automobiles (FGA) based on simulation tools to analyse ergonomic aspects of work-cells already in design phase. Simulation tools allow a deep postural analysis that is one of the main criticism in the design phase. The principles of Digital Human Modeling have been used to develop an easy internal virtual manikin, the Human Model. The tool, based on ISO standards and on a worldwide anthropometric database, allows designers to simulate the most probable postures engaged by operator during work tasks as well as to validate improvements and corrective actions.

Keywords: Human Modeling, ergonomics design, simulation tools

1 INTRODUCTION

The protection of health and safety of worker is a key aspect in the design of production systems mentioned in the current Italian regulation, D.Lgs. 81/2008 (Decreto legislativo, 2008). At article 15 'General measurement of protection', it affirms that the employer shall ensure 'the respect of ergonomic principles in the work organization, in job design, in equipment selection and in the definition of working and production methods, in order to minimize the adverse effects on health of monotonous and repetitive work.' The employer and designers who act on his behalf, are required to adopt suitable methodologies and tools for ensuring that workers will operate under ergonomically correct working conditions. Simultaneously, the new industrial scenario based on key factors as economics, environment, quality, safety, health and work organization requires a new concept of design.

In order to check the compliance of the design approach with current regulation and to maximize the improvements in the key areas of interest, it is appropriate and effective to make use of simulation tools since the design phase.

This objective is a great challenge considering that, according to principles reported in legislation, designers have to achieve a proper worker-work combination in order to respect capabilities and needs of all workers that may operate in the workplace.

To reach this goal, it's much more convenient both from procedural and economic point of view, to adopt robust tools in design phase. In this way it's possible to design in an ergonomically correct way and to continuously monitor if the project retains the ergonomic features reported in legislation. Working on virtual models of future cars and the corresponding production line, it's possible to make changes of in an extremely easy way because don't impact on physical objects (car parts, equipment, etc...) moreover no high costs and short times of changes enforce virtual model use (Miller and Park, 2001).

Simulation tools have to be sufficiently advanced to be adopted also in the re-design of workstations in order to revise unfavourable conditions. Flexible tools lead to achieve improvements in the working conditions as well as to respect the principle of maximum efficacy and cost-benefit balance.

The paper presents a tool based on multi body approach, developed and actually used in Fiat Group Automobiles (FGA) to analyse ergonomic aspects of work-cells already in design phase. This tool allows a deep postural analysis (for example: angle value engaged by joints, traffic light information by comparison to legislation requirements,..) and has proven to have suitable characteristics to meet the needs of proactive ergonomics as well as of corrective ergonomics.

2 THE SIMULATION TOOL: HUMAN MODEL

The tool, called Human Model is a simulation tool for physical ergonomic analysis that supports ergonomic design or redesign of workstations in particular on an assembly line (Geyer and Rösch, 2001). It allows designers to simulate the most probable postures engaged by operator during work tasks as well as to validate improvements and corrective actions.

The principles of Digital Human Modeling (DHM) are at the base of the development of this easy internal developed virtual manikin. Digital human modelling has a forty year old history and many software are commercial available to simulations (for examples: RAMSIS, Jack,...) that are particularly aimed at the automotive industry. These software are almost complex and need an appropriate training and a great computational time. Instead, Human Model is a simple and easily use tool, it can be used by operator with a short training and it gives real time results.

It's an electronic sheet created in Microsoft Excel environment (figure 1) with the support of Visual Basic programming language and therefore it can be integrated with other programs implemented in the same environment .

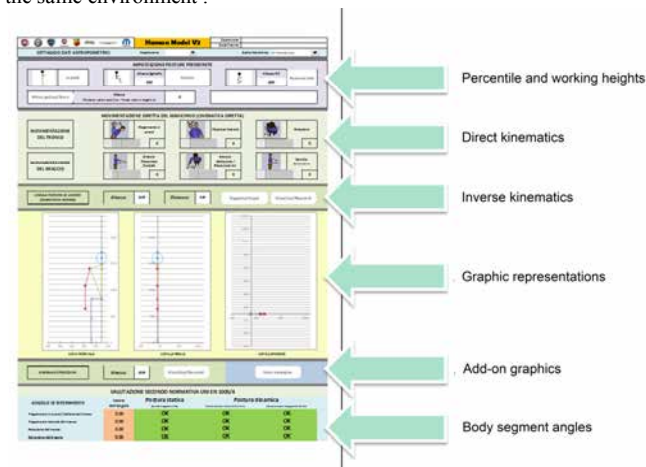


Figure 1: Human Model interface

The tool is based on Multi Body modeling which aims to study systems made of many connected bodies. Manikin structure is in fact an open kinematic chain consisting of rigid segments (body segments) connected by joints characterized by a few degrees of freedom (joints). The worksheet allows to move a 3D virtual manikin using the direct and indirect kinematics and presents some functionalities to estimate the posture of a worker at a workstation.

The principal node, called root, is the pelvis node, all other nodes are derived nodes (sons) (figure 2). This means that imposing a rotation on a upstream node has an impact on all downstream nodes and therefore on the segments connected them (Talamo, 2007).

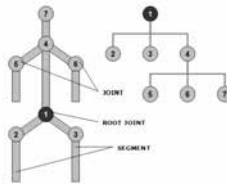


Figure 2: Joints hierarchical structure (Talamo, 2007)

Thus, posture of the upper limbs does not affect posture of inferior limbs and vice versa.

Each node is characterized by one or more degrees of freedom: pelvis and shoulder joints are represented by a spherical joint and have three degrees of freedom, the elbow joint has a degree of freedom while knee and ankle joints have no user-controllable degrees of freedom.

Joint ranges currently implemented in Human Model are data obtained from literature sources and the interaction among articular ranges of various joints is not taken into account. Relating to postures of the lower limbs, tool provides the possibility to select certain configurations: sitting, squatting and upright. The tool implements a worldwide anthropometric database to reproduce different percentile manikins. Dimensions of the segments are obtained by anthropometric measures of the workers' population and they can be changed in real time, to simulate differences for sex and percentiles. The source from which these measures were obtained can be referred to the international standards where statistical tables provides measurements of the human body (differentiated by gender and percentile) of the working population in countries which are ISO members (ISO, 2000; ISO, 2010; Pheasant, 1996). This process ensures the best way to scale the manikin for applications in many countries of the world.

Once the gender and the anthropometric percentile of the worker have been specified and the work heights introduced, the tool simulates the postures that the worker is likely to assume during the execution of the work task and it returns angles assumed by the joints of 3D manikin and a graphic representation of posture on three planes (frontal, sagittal and transverse).

The user can choose between two distinct approaches of use:

1. Direct kinematics: working directly with the cursor on single joints, it's possible to make the manikin to assume the desired posture to reach the working point. Consequently, the tool basically works as a goniometer, computing the angles for each joint to get the desired posture.
2. Inverse kinematics: the operator introduces the presence of constraints (obstacles, restricted space, lower limbs configuration..). The software automatically places the manikin in the required posture to reach the working point. Therefore, the posture assumed by the manikin to reach the working point and returns, as for the direct kinematics approach, angle values for each joint.

To make the tool easy and quick to use, segments connecting joints are not associated with a mass: they were considered as a point model. In addition, some potentially important degrees of freedom, as for example those of the hand, are not represented. The hand is in fact positioned in correspondence of the grasp line at about half of palm.

The virtual manikin can perform most of the movements that a real operator makes during working operations. The main objective is to verify already in the design phase that the work task does not require the engagement of awkward postures.

The tool gives in output numerical values of the angles between the relevant manikin's segments which reproduce the position of the worker.

These outputs can be compared with the limits defined by international standards (figure 3, shows the limits for the back inclination). In this way the user gets a numerical rating (also represented in the classical colour form: red, yellow and green) of the posture related to the work task having so a direct suggestion of how to change design solutions to solve critical postural issues.

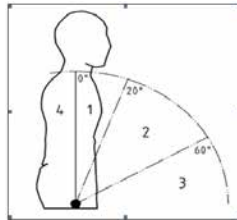


Figure 3: Reference limits for back inclination

Threshold values of body segment angles and their traffic light evaluation are consistent with legislation values (ISO, 2000).

Being though as a screening tool, indication on angles assumed by body segments is not related to the exposure time, that means the tool indicates the presence of awkward postures even if they are engaged for a few instants.

The tool is useful in the design phase of new workstations as well as in the identification of what percentiles may work at an already planned workstation without having to engage in awkward postures. This type of analysis, suggested by many authors in the scientific literature [n], may also help in assigning working tasks to different operators.

The reference percentile chosen for the simulation is 50th percentile male; percentiles reported in literature for design of extremes (1,5,95 and 99 percentile male) and 75 percentile male, indicated by a few authors as the more realist measure of the average worker, were also analyzed (an example of simulation with different percentiles is shown in figure 4).

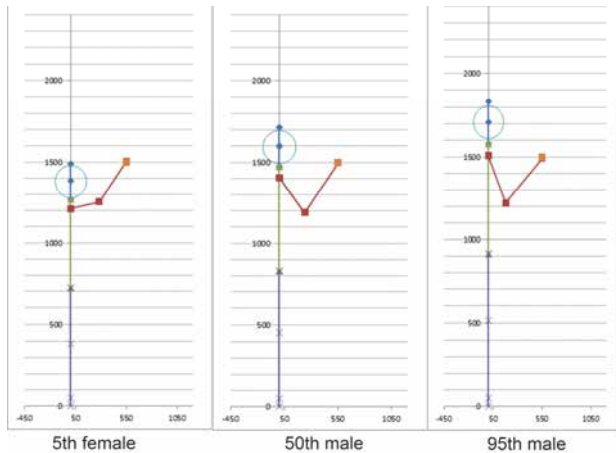


Figure 4: Simulation with different percentiles

Numerical data obtained by the software, can be also given in input for the postural section of more complex ergonomics indices as, for example, EAWS (Schaub et al. 2012a; Schaub et al. 2012b) and

OWAS (Louhevaara and Suurnakki; 1992). In this way, the user can be helped in assessing the work-cell comfort according to the assigned assembly task.

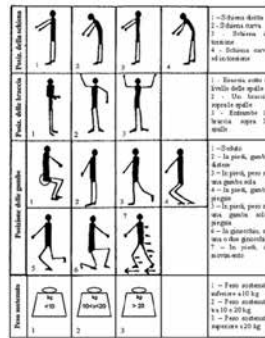


Figure 5: OWAS worksheet

Finally, an extension of the application allows to use the same methodology not only to the individual work-cell but also to an entire section of the assembly line. This function is very important because it allows to analyze and optimize some general features of the production line (as, for example, the altitude) that may have deep impacts on equipment costs.

3 CASE STUDY

The case study presents the use of Human Model during the redesign phase of a workstation to be adapted for a new production. Starting to a preliminary analysis of the pre-existing workstation layout to support the redesign phase simulating different percentiles.

In the first simulation, figure 6a, work heights, to be reached by the operator during such task, have been identified using the initial layout in which the car was on ground level. The particular is mounted on the car by manual screwing and because of the operation requires precision in screws placement, the squatting/kneeling posture was assumed for the operator by operator as the most probable. Indeed such posture allows the operator to gain balance, stability and control for manual handling. The simulation, indicates as critical the value of arm-shoulder angle and trunk rotation; for most percentiles they would assume a value higher than the recommended limit.

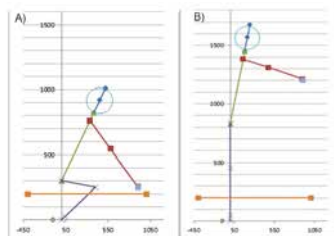


Figure 6: Simulation of working task, 50th percentile

Human Model was used in the analysis of corrective solutions positioning the car at an height from the ground to minimize the number of workers who will have to perform the task engaging in awkward postures. The simulation output values indicate that the car shall be raised from the ground level using a crane. As shown in figure 6b, no critical postures are present when the car is raised from ground level. In the new configuration no biomechanical criticalities for operators are presented regardless of the reference percentile.

4 CONCLUSION

The modern car market is extremely dynamic and so industries must deal with new challenges by updating design and production processes. A detailed analysis of working tasks and workstations is already needed in the design phase because of the new approach of industrial sectors due to the global market scenario. For postural aspects, FGA has internally developed a 3D virtual manikin that allows to perform ergonomic analysis compliant with the most important ergonomics standards.

The tool returns a posture diagram on three planes and allows to compute the angle values assumed by main body segments. Such angles can be analyzed according to the traffic light coding system reported in legislation. Simulations indicated the body segments most critical in terms of biomechanical overload. In this context, the use of an easy simulation tool as the Human Model, is a valid support tool for the design phase to perform preliminary ergonomic analysis on future work-cells in the early phases of a new car development. The simplified structure and the parametric model give flexibility to the tool making it particularly useful in predicting different scenarios for production in terms of location, working population and reference standards.

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Composites and Advanced Manufacturing Methods

FABRICATION OF BINDER-FREE ULTRAFINE WC-6CO COMPOSITES BY COUPLED MULTI-PHYSICAL FIELDS ACTIVATION TECHNOLOGY

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ABSTRACT

A novel sintering method, named as coupled multi-physical fields activation technology, has been introduced for the forming of various material powder systems. Compared with the conventional ones, this technique presents more advantages: lower sintering temperature, shorter forming time, and remarkable inhibition of the grains coarsening. In the study, the cylinders of $\Phi 4.0\text{mm} \times 4.0\text{mm}$ had been formed with ultrafine WC-6Co powders. The relative properties of sintered WC-6Co cemented carbides, such as hardness and the microstructures, had been obtained. The study has shown that a relative density, 97.80%, of the formed samples, could be achieved when the case of temperature 850°C , heating rate 50°C/s , pressure 75MPa and Electro-heating loop 6 times, were used. More importantly, the circumscription for the growth of grain size of WC, attributed to the effect of electrical field, renders coupled multi-physical fields activation technology applicable for getting WC-6Co cemented carbides with fine grain size and good properties.

Keywords: Coupled Multi-physical Fields Activation, Ultrafine WC-6Co powders, Microstructures.

1 INTRODUCTION

WC-Co composites are widely used as cutting tools and dies due to their high wear resistance and toughness (Pan 2011). And WC-Co composites are normally prepared by a powder metallurgy route, which is a procedure consisting of a series of long-time processes, such as synthesis of WC powder, mixing with metal, granulation, pressing and sintering. Moreover, the carbonization temperature of WC is as high as $1400\text{--}1600^\circ\text{C}$. In order to improve its properties and simplify the preparing procedure, the consolidation of WC-Co powder has been studied by a variety of techniques including the hot isostatic pressing (HIP) (Trung 2013), as well as unconventional processes such as microwave sintering and spark plasma sintering (SPS) (Machado 2009), rapid omni compaction (ROC) and ultrahigh pressure rapid hot consolidation (UPRC). However, the hardness and toughness are in

contradiction with each other for the conventional coarse-grained WC-Co alloys (Zhao et al. 2008). To-date, numerous processes have been dedicated to study the densification and grain growth control during sintering of the WC-Co powders in order to achieve the goal of obtaining fully dense WC-Co materials.

One of the keys for controlling the grain growth of WC-Co composites is a suitable selection of additives as grain growth inhibitors, such as Vanadium carbide (VC) and chromium carbide (Cr_3C_2). Meanwhile, the grain growth can be inhibited by using special sintering technologies allowing very high heating rates, increasing the densification rate, even at lower sintering temperature and shorter holding times, such as microwave sintering, spark plasma sintering (SPS), and so on. Moreover, Bonache *et al.* (2011) has investigated the effect of grain growth inhibitors on the WC grain growth and its mechanical properties when they are combined with the use of PECS sintering technique. The results has demonstrated showed that the addition of inhibitors, especially VC, is an efficient method for controlling the grain growth in the solid state, even by rapid sintering processes.

Recently, a coupled multi-physical fields activation technology was proposed for the forming of components for various material systems such as metals, ceramics and WC-Co composites, as illustrated in Figure 1. The advantages of this technique over the conventional ones include lower sintering temperature, shorter forming time, and remarkable inhibition of the grains coarsening. In the coupled multi-physical fields activated sintering, the powders are sintered under simultaneous influences of the current, high temperature and forming-pressure. Firstly, loose powders are placed directly into a die, and then the heating is generated by passing an AC current through the die to providing the necessary temperature in the powders, and a pressure is applied onto the powders at the same time. The whole forming process only took less than 4 minutes. Direct manufacture from powders and no additional binders added to the powders indicate that the proposed technique is an energy conserving and environmentally friendly forming process.

It can be easily noticed the significant differences between the proposed new sintering method and SPS are the amplitude of the electric current, the heating rate and the pressure. Firstly, SPS uses a pulsed electric current to stimulate spark discharge in gaps between the particles. Therefore, the pressure (15-50MPa) applied cannot be too high, otherwise the sparks will disappear. However, the AC current with low voltage and high current, used in the coupled multi-physical fields activated sintering, has little effect on pressure. Secondly, in the proposed sintering method, a heating rate as high as 50°C/s and an electric current as high as 10^5A can be used, which are greatly higher than those used in SPS.

This paper is to report a study on the properties and XRD results of the WC-6Co cemented carbide fabricated by the novel powder sintering method. The microstructure evolution and grain size inhibition are also discussed.

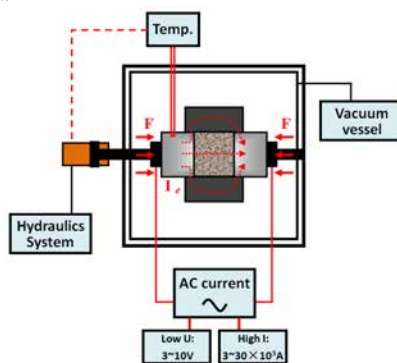


Figure 1: Schematic of the coupled multi-physical fields activation sintering and forming.

2 EXPERIMENTAL PROCEDURES

Commercial WC powder and Co powder (all of them with a 99% purity and an average grain size of $0.3\mu\text{m}$) were used as the raw materials. They were mixed thoroughly with a composition of 94 wt% WC-6wt% Co, and dry milled for 6 hours.

Figure 2 shows the schematic of the tool-set applied in the experiments with a Gleeble-3500D thermal simulation machine from Dynamic System Inc., USA. The machine controls the heating process with a computer-controlled system which is able to preset a value of the heating rate, and the accuracy of the temperature control is within $\pm 3^\circ\text{C}$. The electric field produced by the machine has low voltage and high current (3~10 Volts and 3000~30000A), and the as-received powders consisted of agglomerates which are sufficient to make up a sample with the size of $\Phi 4.0\text{mm} \times 4.0\text{mm}$ (solid cylinder). After weighting, the powder was put into a die. The die model is shown in Figure 2. The die filled with WC-6Co powders was then placed onto the Gleeble-3500D machine, and then it was heated rapidly to a certain sintering temperature at a preset heating rate in a vacuum ($<10^{-4}\text{Pa}$) (a high electric current passes through the die-set and powder system), and at the same time, a preset pressure was applied onto the punch and die-bottom-side. The pressure-temperature profile used during the sintering processing can be found in Figure 3, and hence, the sintering process can be very short, even less than 4 minutes. The detailed technological parameters of the experiment are shown in Table1. The Electro-heating loop means the fluctuation of the temperature and cycles for a fixed times.

The sintered compact's relative density was measured by the electronic analytical balance TP-214. The pore size distributions were observed under a scanning electron microscope JSM-5900LV, JEOL (Japan). And the phases of the synthesized products were analyzed by X-ray diffraction (XRD, D/Max-III A).

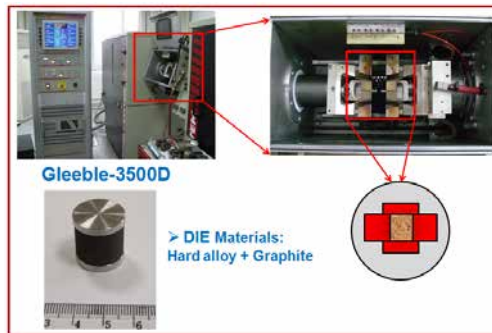


Figure 2: The coupled multi-physical fields activation technology production unit:Gleeble-3500D

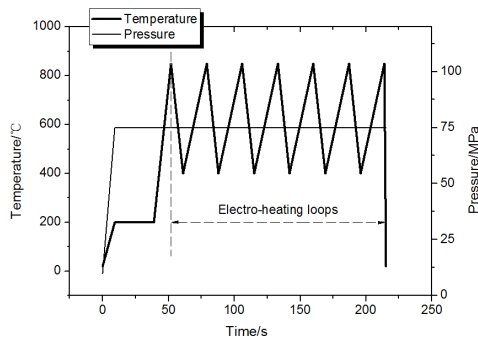


Figure 3: Pressure-temperature profile used during processing of the WC-6Co composites by the coupled multi-physical fields activation technology

Table 1: Process conditions and relative density of the formed samples

Specimen designation	Heating rate (°C/s)	Sintering temperature (°C)	Pressure (MPa)	Times of Electro-heating loop (T~400°C)	Relative density (%)
1#	50	850	75	1	92.90
2#	50	850	75	3	93.30
3#	50	850	75	4	93.80
4#	50	850	75	6	97.80

3 RESULTS AND DISCUSSION

3.1 Properties of the Sintered WC-6Co cemented carbide

The results selected from the experiments can be found in Table 1. The micro-formed samples show high relative density (92.90% to 97.80%). It can be found that dependence of the relative density onto the Electro-heating loop is strong and a tendency towards an increase in relative density as those two parameters was observed. The morphology of a formed sample can be seen from Figure 4.

Table 2 shows properties of WC-6Co cemented carbide material that prepared by different shaping technologies. It could be concluded that the effect of coupled multi-physical fields activation treatment process resulted in a harder sintered product with a relative low strength. This should be attributed to smaller average grain size (Figure 6 (e)) and very small material volumes involved.

Figure 4: The formed samples (solid cylinder) with a size of $\Phi 4.0\text{mm} \times 4.0\text{mm}$

Table 2: Properties of WC-6Co cemented carbide material

Shaping Technology	Relative density(%)	Rockwell A hardness (HRA)
Die pressing (Shi 2006)	97.40	93.1
PEM (Shi, 2006)	97.00	92.8
Die pressing plus CIP (Shi, 2006)	99.50	93.6
Coupled multi-physical fields activation	97.80	87.2

3.2 XRD Inspection of WC-Co System

During the sintering process, the reactions of WC and Co can be shown as follows (Bonache *et al.* 2011):



The XRD pattern of composition WC-6Co samples sintered by coupled multi-physical fields activation technology can be found in Figure 5. The XRD results show that there is no evidence of η

phase ($\text{Co}_3\text{W}_3\text{C}$ or $\text{Co}_6\text{W}_6\text{C}$) formation in the composition. The absence of secondary phases confirms that the WC-Co powder system had been sintered in solid phase. This clearly indicates that the incomplete densification in the solid state can be ascribed to the effect of coupled multi-physical fields activation, especially the high density current field, is associated with the limitation of the diffusion phenomena and migration of Co (Carroll 1999). On the other hand, it is difficult for WC-Co system to react because of the short time of heating period (a few seconds).

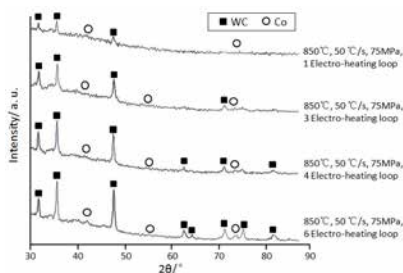


Figure 5: The XRD pattern of composition WC-6Co samples sintered by coupled multi-physical fields activation technology

3.3 Microstructure of the Formed Samples

Comparing the micrographs of the formed samples shown in Figure 6, the following conclusions could be found: (1) WC-6Co powders can be well sintered to dense compacts under the coupled actions from multi-physical fields within relatively short sintering time (e.g. < 4 minutes), while with a conventional sintering it could take a couple of hours.

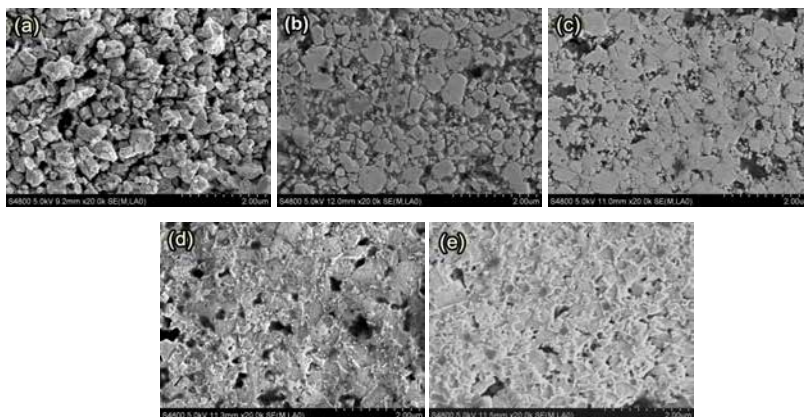


Figure 6: SEM micrographs of formed samples: (a) WC-6Co mixed raw powders; (b) WC-6Co sintered at 850°C, in 50°C/s and under 75MPa for 1 time Electro-heating loop; (c) WC-6Co sintered at 850°C, in 50°C/s and under 75MPa for 3 times Electro-heating loop; (d) WC-6Co sintered at 850°C, in 50°C/s and under 75MPa for 4 times Electro-heating loop; (e) WC-6Co sintered at 850°C, in 50°C/s and under 75MPa for 6 times Electro-heating loop

It is worth to mention that the pores in a composite decrease as the times of the electro-heating loops rise, which accompanies with the densification of compact. At the same time, when the times of the Electro-heating loop increased, the round WC grains combined together with Co binder phase in WC-6Co cemented carbides, for the liquid Co binder phase was formed during the sintering process.

(2) It was found that no coarsening of grains accompanied the process of the densification of the dense compact, obtained from the comparison between the grain size of Figure 6 (b), (c), (d) and (e) and the raw materials grain size of Figure 6 (a). Therefore, the coupled multi-physical fields activation technology is a suitable selection of controlling the grain growth of WC-6Co composites and remaining the good properties of density and hardness.

4 CONCLUSIONS

From the work completed in this study, the following conclusions can be drawn. Compared with conventional sintering methods, the coupled multi-physical activation technology is an efficient process, and it has lower energy consumption and little impact to the environment due to directly forming the component from loose binder-free powders. The WC-6Co cemented carbide can be made using this coupled multi-physical fields activation technology. And the density of the sample made from WC-6Co powder can reach over 97% when they were sintered at a relatively low sintering temperature (850°C), higher heating rate (50°C/s), pressure 75MPa and Electro-heating loop 6 times. The study on the characteristics of the micrographs of the formed samples suggests that the grain growth can be inhibited under the coupled multi-physical fields activations, which is fundamentally different from that in conventional vacuum sintering, as well as SPS. The effect of simultaneous pressure field, temperature field and electric field plays a vital role in controlling grain coarsening.

ACKNOWLEDGMENTS

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MECHANICAL PROPERTIES OF THREE-PHASE POLYAMIDE 6 NANOCOMPOSITES

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ABSTRACT

This work focus on the mechanical properties of three-phase nanocomposites using multiscale reinforcements. The influence of the nano-fillers content, as well as the temperature were studied. Polyamide-6 reinforced with short glass fibre 30 wt.% and with an addition of nanoclay (montmorillonite) and/or nanosilica (SiO₂) were tested in order to characterise their tensile properties at room temperature and at 65°C just above the polyamide 6 glass transition temperature. SEM analysis were conducted on the fracture surface of the tensile bars. SEM investigations showed the importance of the interaction matrix/filler for the material behaviour. Our study also shows that the increase of OMMT percentage in polyamide-6/glass fibre composite made the material more brittle and had a negative effect on the tensile properties. Further, for the silica-based nanocomposites, an optimum was found for a nanofillers content of 1wt.%.

Keywords: Three-Phase Nanocomposites, Polyamide-6, Impact.

1 INTRODUCTION

Nanomaterials are one of the promising technologies of this century. Layered silicates nanocomposites represent more than 50% of this annual consumption, and carbon nanotubes composites 21%. According to the Project on Emerging Nanotechnologies inventory, in March 2011, there were 1317 consumer products based on nanotechnology on market (PEN, 2011).

Nanocomposite materials are an attractive technology because using nano-fillers allows great improvements of the polymeric materials compare to micro-reinforcement, and suit to the goals of industries: produce lighter, thinner, stronger and cheaper structures (Njuguna *et al.*, 2008). The nano-size of the fillers increases the area of contact between matrix and filler and so, reduces stress concentration around the filler. Also, the nano-size presents a very large surface area to volume ratio. For example, it augments the surface area to volume ratio up to 10³ times for a nanofibre compare to a microfibre (Njuguna *et al.*, 2008). It is also significant to note that only 5 wt.% of nanofillers can significantly improve behaviour and properties of a neat polymer (Duval, 2008), compared to at least 20wt.% with glass fibre reinforcement, which allows a reduction of weight and cost.

Among all the properties enhanced thank to nanofillers, we can cite: strength, stiffness, heat-distortion temperature, scratch resistance, thermal, oxidative and dimensional stability, water and thermal permeability, corrosion resistance, surface hardness, barrier properties, flame retardancy and electrical conductivity (Schmidt *et al.*, 2002; Garcés *et al.*, 2000).

Some studies had focused their research on the influence of modified or unmodified clay on polymer nanocomposites' properties (Jimenez *et al.*, 1997; Liu *et al.*, 2003; Yu *et al.*, 2004; Mishra *et al.*, 2009; Zhao *et al.*, 2010). For example, enhancement of mechanical properties of nanocomposites and three-phase nanocomposites are often confirmed. Mishra *et al.* (2009), had shown that Young modulus, tensile strength and elongation at break are increasing with the augmentation of organically modified montmorillonite (OMMT) content (until 3 wt.%) into a polyamide-66 matrix. Silva *et al.* (2012), reported an increase of 32% for the elongation at break for a 30wt.% glass fibre/polyamide-6 filled with 2wt.% of SiO₂ nanoparticles, compare to a classical polyamide-6/glass fibre. Wu *et al.* (2001) found that a polyamide-6/clay with 30wt.% of glass fibre had an enhanced tensile strength of 11% and a tensile modulus enhancement of 42% compared to polyamide-6/30wt.% glass fibre. Further, several parameters were demonstrated to have an influence on these mechanical properties (stiffness, modulus): interaction between the matrix and the fillers (Njuguna *et al.*, 2011), fillers' size (Ng *et al.*, 1999), fillers' volume fraction (Yang *et al.*, 1998), and filler's shape (Garcés *et al.*, 2000).

Others advantages are the cost which is low considering that only a small amount of filler is necessary, and the ease of manufacture without need to change the conventional processing conditions in order to manufacture new products (Njuguna *et al.*, 2008).

2 MATERIALS AND METHOD

2.1 Materials and samples preparation

For this study, two types of three-phase nanocomposites were produced: polyamide-6 (Durethan B30) reinforced by 30% of glass fibre (ThermoFlow672) and particles of SiO₂ (Aerosil R 974), and polyamide-6 reinforced by 30 wt.% of glass fibre and montmorillonite (Dellite 43B, Laviosa Chemicals). In total, seven materials were manufactured with different content of nano-fillers (Table 1). The nano-materials were obtained by direct melting and extrusion in a twin-screw extruder at a maximum temperature of 280°C. The product was cooled in a water bath, pelletized and then dried. From granulates, test samples (crash cones, tensile bars and plates) were injected moulded according to the ISO 527 test standards.

Table 1: Composition of the different studied nanocomposites.

	Type of Matrix	wt.% of PA6	Type of Glass Fibre	wt.% of GF	Type of filler	wt.% of filler
HZ12-01	Durethan B30	65	ThermoFlow 672	30	Dellite 43B	5
HZ12-02	Durethan B30	62.5	ThermoFlow 672	30	Dellite 43B	7.5
HZ12-03	Durethan B30	60	ThermoFlow 672	30	Dellite 43B	10
HZ12-04	Durethan B30	69	ThermoFlow 672	30	Aerosil R 974	1
HZ12-05	Durethan B30	69.5	ThermoFlow 672	30	Aerosil R974	0.5
HZ12-06	Durethan B30	68.5	ThermoFlow 672	30	Aerosil R 974	1.5
HZ12-07	Durethan B31	67	ThermoFlow 673	30	Aerosil R 974	3

2.2 Mechanical testing

Tensile tests, according to the ISO 527 standard were performed in the INSTRON 5500R electro-mechanical tensile-compression machine. Five specimens (flat dumb-bell type A), by materials and temperature, were tested at a speed of 1mm/min. The load was measured with a 100kN load cell and the longitudinal displacement with a laser extensometer. An environmental chamber was used in order to carry out the test at 65°C.

2.3 Scanning Electron Microscopy

The fracture surface of the tensile bars, tested at room temperature and at 65 °C, was analysed with a scanning electron microscope (FEI XL 30) in order to understand the failure mechanism and the relation between the matrix and the filler. The samples were previously coated with gold and palladium.

3 RESULTS AND DISCUSSION

3.1 Tensile properties

Effect of the filler's type

In this work, tensile properties of polyamide-6/glass fibre nanocomposites were investigated. Figure 1 represents the tensile stress vs tensile strain curves for the OMMT-based nanocomposites (graph on the left), and for the silica-nanocomposites (graph on the right). For both filler types, the materials showed a behaviour corresponding to a brittle material without yield point. However, we clearly see that the choice of the filler integrated to the polyamide-6/glass fibre composite, is an important factor. The polyamide-6/glass fibre/OMMT deformed less, the stress vs strain curves report a brittle behaviour with only elastic deformation. Whereas, the SiO₂-nanocomposites were less brittle, the curves present a beginning of plastic deformation before breaking. It is also important to note that OMMT-based composites is stiffer than the silica-based ones. However, the SiO₂-nanocomposites present an ultimate strength and strain at break significantly higher than the MMT-nanocomposites.

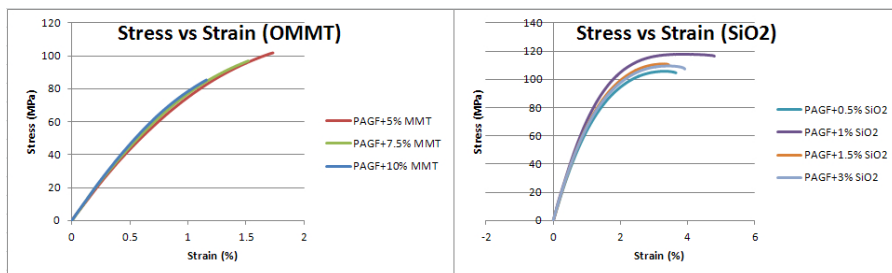


Figure 1: Tensile stress vs tensile strain curves for polyamide-6/glass fibre/OMMT and Polyamide-6/Glass Fibre/SiO₂ at different contents.

Effect of the fillers' content

The main results of the tensile tests for OMMT-nanocomposites are listed in Table 2. At room temperature, with increasing OMMT concentration the Young's Modulus was improved. But, at the same time, the material was less able to resist high load and consequently deformed. Further, it broke at lower stress and strain values as the material became more brittle. These results can be explained by the high content of nanofillers. Akkapeddi (2000), found that above 7 wt.% of nanoclay, polyamide-6 nanocomposites tend to present more fillers aggregates, and he suggested to use a nano-content inferior at 5 wt.% in order to avoid these agglomerates. This can as well give a suitable explanation for the big difference found for the tensile strain at break between a nanocomposite filled with 2 wt.% of nanoclay and the ones filled with a percentage superior to 5wt.%.

Table 2: Tensile properties of the OMMT-nanocomposites at room temperature and 65°C.

	Percentage of Nanofillers	Young's Modulus (GPa)		Tensile Strength (MPa)		Tensile Strain at break (%)		Reference
		RT	65°C	RT	65°C	RT	65°C	
PA + GF + MMT	0%	6.92	-	116.2	-	5.2	-	Silva <i>et al.</i> 2012
	2%	7.61	-	109.7	-	5.1	-	Silva <i>et al.</i> 2012
	5%	9.15	3.56	101.8	60.64	1.73	4.45	
	7.5%	9.69	3.82	96.9	56.83	1.52	4.08	
	10%	9.76	4.67	85.4	56.03	1.16	3.89	

The silica-nanocomposites were prepared at low content of nanofillers (between 0.5 and 3wt.%). Results of the tensile tests for SiO₂-nanocomposites are presented in Table 3. At room temperature, we could see that the material which has the best properties is the glass fibre filled polymer with 1 wt.% of nano-SiO₂. It was the only nanocomposite which shows an improvement in both the tensile strength and the modulus compared to glass fibre/polyamide-6, and it had the higher tensile strain at break. These results are in line with the findings of Zhou *et al.* (2008), for nano-silica/polypropylene composites. They reported an optimum between 0.4 and 0.8 vol.% of SiO₂, according to the treatment undergone by the filler.

Table 3: Tensile properties of the SiO₂-nanocomposites at room temperature and 65°C.

	Percentage of Nanofillers	Young's Modulus (GPa)		Tensile Strength (MPa)		Tensile Strain at break (%)		References
		RT	65°C	RT	65°C	RT	65°C	
PA + GF + SiO ₂	0%	6.92	-	116.2	-	5.2	-	Silva <i>et al.</i> 2012
	0.5%	7.78	-	105.7	-	3.65	-	
	1%	8.40	3	117.8	73.55	4.79	9.12	
	1.5%	7.95	4.46	110.9	67.83	3.43	7.54	
	3%	7.94	4.78	109.5	66.93	3.91	7.45	

Effect of the temperature

Figure 3 shows the difference between the tensile stress vs tensile strain curves at room temperature and at 65°C for the polyamide-6/glass fibre filled with 5 wt.% of OMMT and the one filled with 1.5wt.% of SiO₂. We can notice that the shape of the curve is similar for the OMMT-nanocomposites and the SiO₂-nanocomposites, even if the values are still lower for the OMMT one.

For OMMT-nanocomposites, the same trend concerning the nanofillers percentage (Table 2) can be noticed at 65°C than at room temperature. However, at this temperature, the material is more ductile than at room temperature which is a typical behaviour for a polymeric material especially when the temperature is above its glass transition. For a polyamide-6 matrix, the glass transition temperature was reported to be between 40°C and 50°C (Nielsen *et al.*, 1994). The modulus is almost halved, the tensile strength is lower, and it strain at break increases by a multiple of 2.5 or more.

The SiO₂-based nanocomposites also behave as a ductile material at 65°C. The tensile strength and strain at break follow the same trend than at room temperature and decrease when the nano-silica percentage increase. However, the modulus increase with the SiO₂ content.

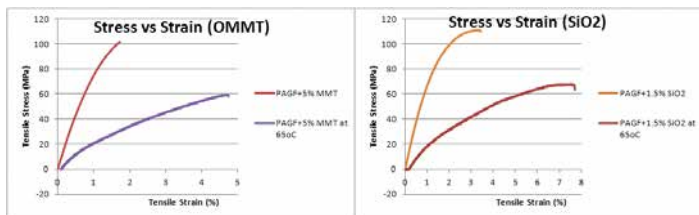


Figure 3: Tensile stress vs tensile strain curves for OMMT-nanocomposites (5 wt.%) and SiO₂-nanocomposites (1.5 wt.%) at room temperature and 65°C.

3.2 Scanning Electron Microscopy

The SEM investigations explain the fracture behaviour of the studied nanocomposites. In the case of OMMT-nanocomposites, at room temperature, we can see a lot of pull-out of the fibre (Figure 4a). The matrix underwent only elastic deformation, and we can notice that the surface is typical from a brittle fracture. However, Figure 4b shows that, for silica-nanocomposites at room temperature, the matrix was plastically deformed. The matrix/fibre adhesion was very strong (Figure 4c), so the glass fibres had to break instead of just pulling-out of the matrix. This explains the higher strength of nano-silica reinforced polyamide.

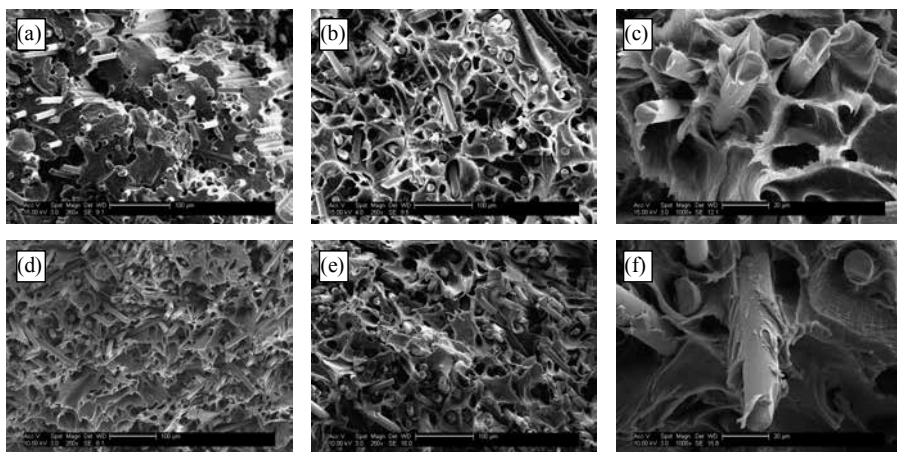


Figure 4: SEM pictures of the tensile fracture surface (a) OMMT-nanocomposite at room temperature, (b) silica-nanocomposite at room temperature, (d) OMMT-nanocomposites at 65°C, (e) silica-nanocomposite at 65°C, and zoom at the glass fibre for silica-nanocomposites (c) at room temperature, and (f) at 65°C.

The fracture surfaces of the tensile bars tested at 65°C for both OMMT and nano-silica composites correspond to a ductile fracture with plastic deformation and drawing of the matrix. We generally noticed more fibre breakage and only few fibre pull-out. However, even at 65°C the fibre/matrix interaction was weak for the OMMT-nanocomposites, as we found only clean fibres. For the nano-silica composites, a lot of matrix' traces were found stuck on the fibre (Figure 4f), which again can explain the higher strength for these materials compared to the composites with OMMT.

4 CONCLUSION

The aim of this study was to identify the effect of the nano-fillers (type and content) on mechanical properties as well as the influence of the temperature. It was shown that the increase of OMMT percentage in polyamide-6/glass fibre composite made the material more brittle and had a negative effect on the tensile properties. It could be explained by the weak interaction between the matrix and the fibres observed thanks to SEM pictures. The high content can as well create nanofillers aggregates and so make the material more brittle. For the nano-silica addition in polyamide-6/glass fibre, the nanocomposites with 1 wt.% of SiO₂ presented the best tensile properties. As for classic polymeric materials, increasing the temperature made all the nanocomposites more ductile. This is confirmed by the SEM pictures which show that for OMMT-nanocomposites, the fracture surface is brittle at room

temperature, and became ductile at 65°C. To general, it can be said that the integration of secondary nanofillers is a good way to enhance the mechanical properties of PA composites, however the percentage and type of filler play a crucial point.

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THE EFFECT OF TEMPERATURE CHANGES ON TO QUASI-STATIC TENSILE AND FLEXURAL PERFORMANCE OF GLASS FIBRE REINFORCED PA66 COMPOSITES

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ABSTRACT

A significant method of reducing CO₂ emissions in road vehicles is to reduce the vehicle mass. One means in which this can be achieved is to adopt lightweight materials such as thermoplastic composites. Thermoplastics offer advantages in term of weight when compared to conventional steel and aluminium casting. In this study thermal mechanical testing has been conducted on two types of commercial polyamide 66 (PA66) with 35 wt.% short glass fibre reinforcement. One of the materials was impact modified with an elastomer to increase material toughness. Experimental results showed both the reinforced PA66 materials to be temperature dependent. All test results demonstrated the trade-off in the mechanical properties of the two materials especially the impact modified. PA66 with 35 wt.% short glass fibre exhibits the best tensile strength, flexural strength and modulus for each temperature tested. Whereas the impact modified PA66 with 35 wt.% short glass fibre exhibits the higher strain and toughness for each temperature tested.

Keywords: Thermoplastic; Polyamide 66; Short Glass Fibre Reinforced.

1 INTRODUCTION

Recent interest in developing highly fuel efficient vehicles with low emissions has focused efforts toward materials. Materials used for automotive components traditionally consisted of metals in regard to their established use in most engineering industries, better understanding of application and manufacturing processes. As weight reduction is now seen as vital area that automotive industries can now exploit to achieve fuel efficiency and reducing CO₂ emissions (Park et al. 2012). Lightweight polymers have been used to replace metal counter parts over the last few decades from interior trim to external body panels (Araújo et al. 2003, Mouti et al. 2010). Under bonnet fluid reservoirs and tubing is common place for polymers but a need for structural under bonnet components that perform better and longer at less weight and cost to metal counter parts has opened a growth area for injection-

mouldable fibre-reinforced thermoplastics. Among the most challenging of under bonnet applications is the engines oil pan. As it is mounted low on the undercarriage where it is subject to stones and gravel kicked up by tires. Most oil pans have a structural requirement needing fairly complex internal and external geometries, which in metals can translate to heavy multi-piece assemblies produced in numerous manufacturing steps. Work has already been done to optimised material properties for an oil pan using polyamide 66 (PA66) 35 wt.% short glass-fibre-reinforced with an elastomer modifier to improve impact resistance (Mouti 2012, Mouti et al. 2010). But the toughness of PA materials are temperature dependent and characteristic of brittle tough transition temperatures have been identified of several PA6 compounds containing glass fibres (Araújo et al. 2003, Kroll et al. 2013). The next step is to understand the effects of different temperatures conditions that the polyamide 66 material systems need to cope with for a range under the bonnet applications that metals have yet to be replaced. Therefore this study aims to investigate the properties of two PA66 35 wt.% short glass fibre reinforced materials one of which has been impact modified with an elastomer. The test strategy in this work is to use temperature as the variable to determine effects of different thermal conditions of each material at an experimental level. The results can then be used to develop new material grades to address deficiency's based on application requirements.

2 EXPERIMENTAL

2.1 Materials and Sample Manufacturing

Two commercial grades of polyamide 66 with 35 wt. % of discontinuous glass fibre, Ultramid® A3HG7 and Ultramid® A3ZG7, (henceforth denoted as Material A and B respectively) were supplied by BASF. Material B was elastomer toughened and has been blended as co-polymer into the base PA66 material full details of this process are kept as a trade secret. The rubber toughening is also kept as a trade secret by BASF although using literature three elastomers have been narrowed down that can be compounded with polyamide and are cost effective which are Acrylonitrile Butadiene Styrene (ABS), Ethylene Propylene Rubber (EPR) and Ethylene Propylene Diene Monomer (EPDM) (Laura et al. 2000; Karayannidis et al. 2002; Ren et al. 2009; Wong et al. 2002). The graft copolymers produced aids dispersion, creating separate phases in the solid enhancing interfacial adhesion. The glass fibres have an average length (l) of 300 μm and diameter (d) of 13 μm , thus yielding an average aspect ratio (l/d) of 23. Test samples were manufactured using injection moulding to suit ISO standard 527 (tensile) and 178 (flexural) for shape and size. **Figure 1a** illustrates specimens used for the testing with attached retro-reflective tape. Flexural test specimens were fabricated by injection moulding which complied with ISO 178 for shape and size, see **Figure 1b** for specimens used in the testing. All test samples in this study come from the same batch of material.



Figure 1: Sample types used: a) tensile dumbbell; b) flexural bar

2.2 Tensile and Flexure Tests

Tensile testing was conducted following ISO standard 527, testing speed for all specimens was 1 mm/min and sample shape was type 1A and the samples were tested unconditioned. To gain accurate strain data for tensile testing retro-reflectors were attached to the specimens 50 mm apart ± 2 mm to suit the specimen type 1A gauge length in ISO 527. The flexure testing was conducted following ISO standard 178 and all specimens were tested at 2 mm/min with a size of 80x10x4mm. Testing conditioning was done using different temperatures as follows 23°C, 65°C, 90°C and 120°C. Temperature selection: The typical standard air temperature of 23°C in ISO 291 is the most common test temperature conducted which allows other work to be compared and can represent the temperature of an engine before it has started on a normal day. 65°C was selected as a middle ground between 23°C and 90°C. 90°C was selected based on a typical oil operating temperature. An IC

engine runs around 90°C to 100°C which is based on SAE J300 standards test Kinematic Viscosity of engine oil at 100°C. Also the temperature of the oil in a big end bearing is around 100°C which is the most highly stressed part of an ordinary car engine. 90°C was selected as a nominal for high oil film temperature that materials should be tested to as oil will start to cool once it has passed from the top to the bottom of the engine. 120°C was selected in a case of engine overheating and if accumulative temperatures were to build up. Each temperature was checked using a K-type thermocouple on the specimen surface before starting each test. Testing was conducted on an Instron 5500R screw driven universal test machine using a 30 kN load cell and a laser extensometer for tensile testing.

3 RESULTS AND DISCUSSION

Tensile test data was captured from each material tested. Tensile test data was then used to plot stress strain relations. Data captured from the universal testing machine and the laser extensometer was plotted in **Figure** showing the relationship between stress and strain.

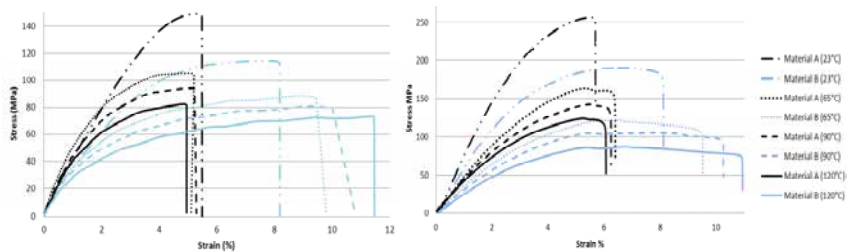


Figure 2: Plotted stress and strain results Left tensile data; Right flexure data.

There is a clear difference on how the elastomer modifier in material B affects toughness by allowing the material to achieve higher strain before failing but loses maximum stress when compared to material A. Results for material A at 23°C are in agreement with the literature (Mouhmid et al. 2006) for PA66/short glass fibre 35 wt.% tested at 20°C. There is complete disagreement when comparing both materials A and B to work done by Mouti under similar conditions. Explanations for some of the discrepancies could have come from the storage of the test specimens which could have degraded from a two year shelf life including thermal degradation (Pielichowski and Njuguna 2005); moisture uptake (Mouti 2012); and strain rate dependency due to difference in testing speeds of 2 mm/min (Mouti 2012) against 1 mm/min in present work. Material A results at 65°C, 90°C and 120°C showed consistency with each other for their curve characteristic with a 10% stress step between each temperature increase when comparing to 23°C. Strain results for all tests done on material A failed with 11% range of 23° to 120°C suggesting material A has good stiffness across a range of different temperatures. Material B's curves share similar shape characteristics with each other with decreases in stress and strain in expansion related to increases in heat. At 65°C, 90°C and 120°C test, the plotted results displays wavy curve. This could relate to the thermal chamber turning on and off to regulate the temperature for the experiment and which could introduce an oscillation effect in the results. With increases of temperature material B becomes more ductile and less stiff with a decrease in tensile strength. Temperature clearly affects properties of the Material A. This can be seen in **Figure** left stress versus strain. 23°C results perform the best out of all the temperatures tested demonstrating better toughness. Temperatures 65°C, 90°C and 120°C show a 28% to 46% in tensile strength reduction to 23°C which means a loss in toughness is affected by the increase of temperature. The results from material A testing do go in line with expectations where an increase in temperature is likely to reduce tensile strength. Load and stress were likely to decrease with an increase in temperature and extension and strain will react less as the material is stiffer without being impact modified. Temperatures also clearly affect the properties of material B as well when looking at **Figure** left stress versus strain. 23°C results perform the best out of all the temperatures tested for strength but not for extension as this increased the most at 120°C offering about the same level of

toughness for each temperature tested. Temperatures 65°C, 90°C and 120°C show a 23% to 36% in tensile strength reduction to 23°C which means a loss in toughness is affected by the increase of temperature. The results from material B testing do go in line with expectations where an increase in temperature is likely to reduce tensile strength. Tensile stress was also likely to decrease with an increase in temperature and extension and strain will increase from the material becoming more ductile. This information also demonstrates the trade-off's in the mechanical properties of the two materials when one of the materials has been impact modified with an elastomer. Flexural test data was captured from each material tested. Flexural test data was then used to plot stress strain relations. Plots showed a clear difference between the two materials tested across the range of temperatures tested. **Figure** right showing the relationship between stress and strain. There is also an obvious stress difference for material A and B tests done between 23°C and 65°C which could be put down to the temperature increase of 42°C between the 23°C and 65°C set of tests. Material A showed little variation to strain from each temperature tested compared to each temperature tested on material B. This can be put down to the elastomer filler which allows material B to strain further when temperature is increased, whereas material A has some stability most likely gained for the addition of glass fibre in a PA66 matrix. Temperature clearly affects properties of the material A. This can be seen in **Figure** right stress versus strain. 23°C results perform the best out of all the temperatures tested demonstrating better stiffness. Temperatures 65°C, 90°C and 120°C shows a 36% to 52% in flexural strength reduction to 23°C which means a loss in toughness and is effected by the increase of temperature. Material stiffness can be considered good as the average strain works out at 6.1% with a deviation of $\pm 0.3\%$. The results from material A testing does go in line with expectations where an increase in temperature is likely to reduce tensile strength, load and stress were likely to decrease with an increase in temperature and extension and strain will react less as the material is more stiff without being impact modified. Temperatures also clearly affect the properties of material B as well when looking at **Figure** right stress versus strain. 23°C results perform the best out of all the temperatures tested demonstrating better toughness and stiffness. Temperatures 65°C, 90°C and 120°C show a 37% to 46% in flexural strength reduction to 23°C which means a loss in toughness is affected by the increase of temperature. The results from material B testing do go in line with expectations. The expectation was increases of temperature were going to make the material more ductile reducing flexural strength load and stress but increasing extension and strain before failure. Material A shows better strength to material B but has much lower strain values making material A less tough then material B. This can be seen in **Figure** right. The test results also demonstrate the trade-off's in the mechanical properties of the two materials when one of the materials has been impact modified with an elastomer. Using results from (Mouti 2012) flexural testing at 23°C shows much closer similarities for both materials when comparing to this work, unlike the tensile testing. There is some discrepancy between maximum stresses but strain could be considered a lot more similar. A reason for this is that the test speeds are both the same at 2 mm/min.

3.1 Failure Mechanism

The tensile failure mechanism is a single brake with no necking, chipping or strain marks at the brake point. The failure itself can be defined as a brittle fracture in agreement with (Mouhmid et al. 2006) and can be explained by the contribution of the glass fibre as a brittle tough material. Each material and temperature tested showed consistent peak loads for each specimen but both materials show deviation on the extension by ± 0.4 mm. The flexure failure mechanism for the bar samples all failed at the mid-point of the 3-point bending test as to be expected. Samples remained intact with a rupture failure on the corresponding surface to the central point which was coursed from a tensile function.

3.2 Morphology Studies

SEM micrographs were taken of the fracture surface of the samples represented from the tensile and flexure tests. The predominant failure mechanisms are fibre pull out and matrix plastic deforming (ductile pulling/tearing). Fibre pull-out, matrix plastic deforming and matrix brittle fracture is evident across all micrographs taken of material A (**Figure** 3a-b). Matrix pull away, fraying, voids and plastic deforming is evident across all micrographs taken of material B (**Figure** 3c-d). Temperature increases for material A would also appear to affect the extent fibre pull out length. A course for this is poor

matrix surface adhesion to the glass fibres as the fibres been pulled out are cleaner at higher temperatures. This could be linked to why flexural strength is reducing for each increase in temperature. This completely differs when an elastomer is used to reinforce a matrix (material B) as at low temperatures there is less adhesion to the fibre surface but increases in temperature sees the matrix holding and maybe pulling out with the fibres together also allowing the material to flex much further before failing. As for material B reduction in mechanical strength which contradicts the statement made for material A it is likely the elastomer in the matrix is becoming more ductile for each temperature increase, reducing its maximum flexural strength so even though the elastomer is offering better fibre adhesion in the matrix material the elastomer is becoming more ductile reducing maximum flexural strength. **Figure 3a** shows little pull out and brittle fracture at lower temperatures were as **Figure 3b** show longer fibre pull out and matrix plastic deformation of material A at higher temperatures. All micrographs taken of material B shows the matrix having strong bonding to the glass fibres in each test temperature. Voids in the matrix are easily found in material B temperatures at higher temperatures which be seen in **Figure 3 d** typical surface found at 90°C and 120°C. This could be linked to the specimen fabrication process as micro defects in the injection moulding process. But the voids could also be present for specimens tested at 23°C and 65°C but are hidden due to matrix plastic deforming but propagated as fraying instead **Figure 3c** typical surface found at 23°C and 65°C. Assuming voids are present in tests conducted at 23°C and 65°C where the fraying does look fibrous which maybe causing its own elastomer fibrous pull out leaving voids from a fibrous ripping function. The fibrous ripping function producing voids which can be summed up as dispersion of soft inclusions in a rigid matrix and as a result of dilatation and elongation processes the post-failure fracture surfaces exhibit holes or cavities where the deformed and ruptured particles have relaxed back into holes larger than the original particle size.

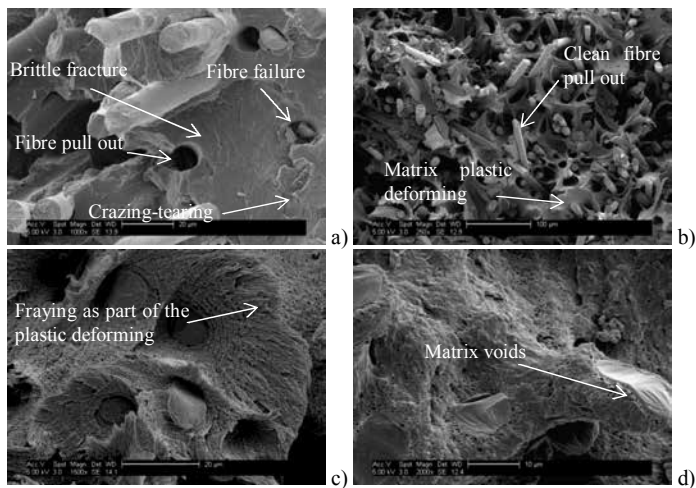


Figure 3: SEM micrographs of the typical fracture surfaces of material A (a-b); material B (c-d)

4 CONCLUSION

In this study, the influence of temperature on quasi-static tensile and flexural properties of 35 wt.% short glass fibre reinforced PA66 have been investigated. The uses of material A would be better suited to structural applications as it demonstrated the least amount of deflection and remained close to the 5.2% strain range for each temperature tested for tensile and a 6% strain range for flexural. Whereas material B strain increased with an increase in temperature as to be expected due the addition of an elastomer, removing some of the stability that glass fibre offered to PA66. This would make material B better suited to applications that requires better impact resistance. Material A exhibits the best strength and modulus across each temperature tested. Testing conducted at 23°C

gained the best toughness properties for both the materials whereas increases in temperature from 23°C up to 120°C reduced toughness properties for material A. Material B would have lost toughness when stress reduces, but levels out as strain increases with every temperature increase so toughness remains almost the same for each temperature increase. The test results also demonstrate the trade-off's in the mechanical properties of the two materials when one of the materials has been impact modified with an elastomer. In this case mechanical strength is reduced for material B but gained much higher strain across all temperatures tested. Clear differences in material properties and plots can be observed in all results. Both materials show the same failure mechanisms for both tensile and flexural studies. SEM micrographs from tensile and flexure testing demonstrated the elastomer in material B had better glass fibre adhesion allowing higher strain and extension which give the material system more toughness and which also improved with each increases in temperature as the elastomer became more effective. The addition of elastomer weakened material B's total strength compared to material A. Material A loses surface adhesion as temperatures were increased shown as long fibre pull out as well as cleaner fibres from pull out. The edition of elastomer effected the plastic deformation on the matrix material as it was more fibrous.

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EFFECT OF FIBRE TREATMENTS ON MECHANICAL PROPERTIES OF FLAX/TANNIN COMPOSITES

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ABSTRACT

Due to the inherent environmental benefits of using natural resin (tannin) and natural fibre (flax), flax/tannin composites could be potentially used for vehicle applications. One of the main limitations is the hydrophilic property of flax, resulting in the poor fibre/hydrophobic matrix interface quality. Alkali, acetylation, silane treatment and enzymatic treatment were selected to modify non-woven flax mats to prepare the composites. The fibre morphology was studied through scanning electronic microscopes (SEM). The effects of fibre pre-treatments on dynamic and static mechanical properties of composites were investigated through adequate experiments, such as dynamic mechanical analysis (DMA) and static tensile testing. The modified rougher fibre surface broadened the glass transition peaks of composites due to the improved surface adhesion. However, there is no big improvement of tensile strength after modifications. The pure NaOH (sodium hydroxide) treated composites remain the tensile properties and offer good flax/tannin wettability.

Keywords: Flax/tannin, fibre treatments, mechanical properties.

1 INTRODUCTION

Natural fibre-reinforced fully bio-composites have attracted the interest of many industries due to their comparative mechanical properties and outstanding bio-degradability characteristics (Fan *et al.* 2011; Kalia *et al.* 2011). The composite made from tannin and flax fibres could potentially offer desirable characteristics aiming at reducing the environmental footprint of superlight electric vehicles through the use of bio-materials for load-bearing parts such as vehicle body panels, crash elements, side panels and body trims (Zhu *et al.* 2012; Avril *et al.* 2012). However, the incompatibility between hydrophilic flax fibre and hydrophobic tannin resin limits their interphase quality and hence the mechanical properties. Mercerization, acetylation, silane treatment, and other fibre pre-treatments are commonly used for flax composites to solve the problems (Van de Weyenberg *et al.* 2003).

Flax fibres are amenable to chemical modification due to the presence of hydroxyl groups. The hydroxyl groups may be involved in the hydrogen bonding within cellulose molecules, thereby activating these groups or can introduce new moieties that form effective interlocks within the system. The interfacial properties can be improved by giving appropriate modifications to the components, which give rise to changes in physical and chemical interactions at the interface.

The suitable treatment on flax fibres may improve the mechanical performances of the final composite mechanical performances. Alkali treatment of natural fibres, also called mercerization, is

the common method to produce high-quality fibres. From the recent investigation, it is the alkali concentration that mainly controls the extent of mercerization, influencing the molecular compositions. The sufficient alkali concentration for the treatment is 5-10% NaOH for hours followed by rinsing and drying. Acetylation is a well-known esterification method originally applied to wood cellulose to stabilize the cell walls against moisture, improving dimensional stability. Coupling agents usually improve the degree of crosslinking in the interface region and offer a perfect bonding. Xie *et al.* (2010) have reviewed silane coupling agent modification to natural fibre composites and found out improvements in strength, moisture absorption and fungal resistance for epoxy composites. The suitable silane modification for fibres in epoxy composites was aminopropyl triethoxy siloxane (APS) and for methacryloxypropyl trimethoxysilane (MPS). Enzymes are an increasingly interesting option as such or when combined with chemical and mechanical methods for modification and processing of biomaterials. The laccase-catalysed modification can be used to tailor the properties of various lignocellulosic materials, including flax fibre materials based on the application needs (Kim and Cavaco-Paulo 2012). Lauryl gallate, a hydrophobic compound with strongest internal sizing effect, were grafted on cellulosic fibres, and the results showed significant reduction of water penetration (Garcia-Ubasart *et al.* 2012; Garcia-Ubasart *et al.* 2011).

In authors' study, flax fibres with five different surface treatments were firstly applied with tannin resins. The mechanical properties of the final composites were investigated through DMA and tensile tests. In order to understand the treatment effects, the fibres surface were also examined through SEM.

2 MATERIALS AND EXPERIEMENTS

2.1 Materials

Non-woven flax fibre mats with different surface treatments were supplied by Valtion Teknillinen Tutkinuskesku (VTT). The mercerization was made by immersing the flax mats into 5 w-% NaOH solution for two hours, washing them two times thoroughly with water and drying in 50°C for 12 h. This NaOH treatment was made as pre-treatment also for butanetetracarboxylic acid (BTCA) and amiopropyltriethoxysilane (APS) treated mats. The BTCA treatment was done by spraying 1% BTCA-water solution on both mat surfaces to an amount respecting 5% of BTCA on fibres. APS treatment was made for moist mats by spraying 1% APS in ethanol-water solution (80:20) on both mat surfaces. Treated and untreated non-woven flax mat reinforced tannin composites manufactured by compression moulding were provided by University of Lorraine-ENSTIB (Table 1). Two mat layers were used in each composite to obtain 50 wt% of fibre/resin ratio.

Table 1: Investigated flax composites and associated flax mats.

Composite type	Treatment method	Studied fibre mat
T	None	Yes
1	5% NaOH	Yes
2	NaOH+BTCA	Yes
3	NaOH+APS	Yes
4	Laccase	No
5	Laccase-Doga (LD)	Yes

* BTCA- Butanetetracarboxylic acid, APS- Amiopropyltriethoxysilane, Laccase-Benzenediol, Doga-dodecyl gallate.

2.2 Characterisation and tests

2.2.1 Scanning Electron Microscopy (SEM)

Fibres were extracted from the treated and untreated flax mats, and then were examined using a XL30 SFEG analytical high resolution scanning electron microscopy (SEM), supplied by FEI.

2.2.2 Dynamic mechanical analysis (DMA)

Each composite specimen of 35×12 mm was placed in a Thermal Analysis Instruments Q800 DMA using single cantilever bending mode and liquid nitrogen cooling system. The temperature was heated from room temperature to 200°C at a heating rate of 3°C/min and a frequency of 1 Hz.

2.2.3 Quasi-static tensile testing

Tensile tests (at least three specimens each group) according to ASTM 3039 were carried out using a universal Instron 500/100 machine with the head speed of 2 mm/min. The gauge length was 150 mm. Digital image correlation (DIC) method were used for micro-strain investigation.

3 RESULTS AND DISCUSSION

3.1 Fibre surface morphology

The SEM clearly shows differences in the surface morphology of the flax fibres depending on the applied fibre surface modifications, including 5% NaOH, BTCA, APS and Laccase-Doga (LD). Figure 1 provides details about the surface characteristics of flax fibres with and without chemical treatments.

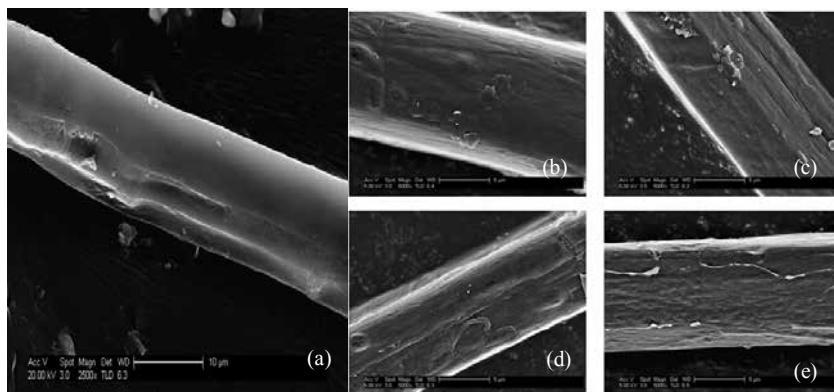


Figure 1: SEM morphologies of flax fibres: (a) untreated; (b) NaOH; (c) NaOH-BTCA; (d) NaOH-APS; (e) Laccase-Doga.

From Figure 1(a), the untreated fibre structure was not clear and partially covered by attached smooth substances, such as fibre waxes and fats. A very effective procedure to purify the flax fibres is alkalization using NaOH, resulting in the removal of waxy, the primary cell wall and other additives. It can be seen from Figure 1(b) that the resultant fibre surfaces were more structured with obvious striations as the lamella ordered by flax fibre fibril. The clear cut difference in the surface morphology is due to the dissolution of lignin, hemicellulose, and waxy materials which increases the inter-fibrillar region and imparts a rough texture to surface (Yan *et al.* 2012). The knuckle –swellings and disclimation as present in the raw fibres can still be found after NaOH-treatment. It is reported that the higher NaOH concentration (10%) may start the conversion of the crystalline form from cellulose I to cellulose II, which causes deeper and broader striation (Yan *et al.* 2012). The surface features of fibres were also clearly visible for other three modifications (BTCA, APS and LD). In addition, more structure of raw fibre cell wall on the three treatments was exposed on the fibre surface than that of the NaOH-treated flax fibre. Another thing noted for LD fibre was the thin layer with many small protrusions, which were considered as the grafted hydrophobic Doga compounds. In conclusion, the rougher fibre surfaces have the potential to improve the fibre/matrix adhesion.

3.2 Effect of treatment on dynamic mechanical properties of composites

Dynamic mechanical analysis done in the experiments studied the effect of fibre surface treatments on the temperature dependency of viscoelastic properties of flax/tannin composites. Figure 2 shows the testing curves corresponding to storage and loss modulus-. transition temperatures (shown in Table 2) were determined based on these figures.

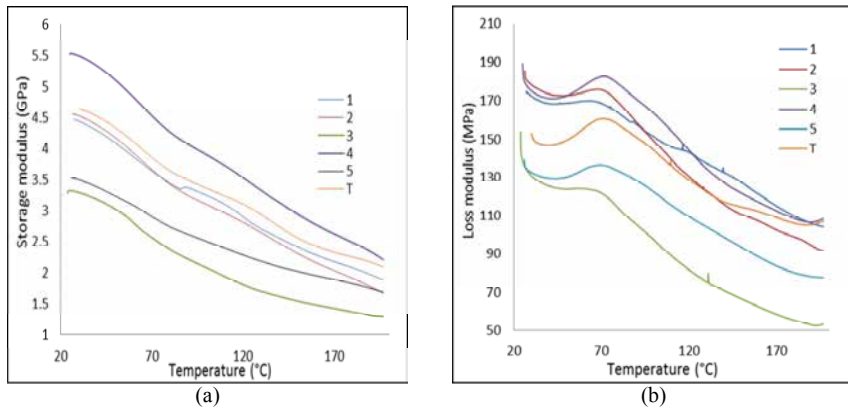


Figure 2: DMA curves : (a) storage modulus-temperature; (b) loss modulus-temperature.

Table 2: Part of the obtained DMA quantitative values,

Types	E' at 27°C (GPa)	E'' at 27°C (MPa)	T _g (loss modulus) (°C)
1	4.4	174	63
2	4.5	181	67
3	3.3	134	64
4	5.5	178	70
5	3.5	135	69
T	4.6	153	71

For composites, storage modulus directly refers to the elastic characteristic highly influenced by the fibre/matrix adhesion. From Figure 2(a), the initial storage modulus of composites at 27°C varied quite a lot as a result of different fibre treatment techniques employed. The type 4 composite showed higher storage modulus of 5.5 GPa, compared with the storage modulus (4.6 GPa) of type T (unmodified) composite. Clearly, Laccase treatment for type 4 has a significant positive effect on the interfacial bonding due to the rougher fibre surface topography after partially or completely removing the non-cellulose lignin during processing. Except for type 4, the other modified composites including type 1, 2, 3 and 5 exhibited lower storage modulus at 27°C than the type T composites. The complex structure of flax fibres makes it difficult to give a precise and accurate explanation for the resultant variation in initial storage modulus. The rougher fibre enlarges the fibre/matrix contact surface, improving the load transfer, while the rearranged or re-oriented fibrils would lead to a better stress/load carrying ability along the fibre axis; also the reduced fibre length/diameter ratio allows the fibre reinforcement more efficiency. However, the stress transfer between fibrils could possibly decrease by weakening the interfibrillar matrix materials, such as lignin and hemicellulose, leading to loss of storage modulus.

The most important transition temperature obtained from DMA analysis is the glass transition temperature (T_g), which could be read from loss modulus curves. Loss modulus represents the viscous portion of materials and reaches a maximum value at the glass transition. This T_g is reported to be more reliable because the T_g obtained at the tanδ peak overestimates glass transition temperature. The T_g of type T (unmodified composite) was found at around 71°C, while the other T_g were in the range

from 60 to 70 °C. The similarity of T_g reveals that the surface treatments have little change on the overall mobility of tannin resins. Some unusual small sharp peaks occurred in both loss modulus of type 1, type 3 and type T composites. The reason has not been determined but possibly is the post-cure of tannin resins or other cross-linking reactions. Compared to the type T composite, a significant change in the treated-flax fibre composites is the broadening of the T_g peaks, attributed to the improved internal adhesion increasing the modulus gradient of tannin resins. The resin layer on the fibre surface showed higher modulus than the rest.

3.3 Effect of treatments on tensile properties of composites

The effects of fibre surface modifications on tensile behaviour of flax/tannin composites were studied. The possible changes in flax/matrix adhesion is factor for mechanical performances of composites after fibre treatments. The tensile strength and modulus of flax/tannin composites are summarized and showed in Figure 3.

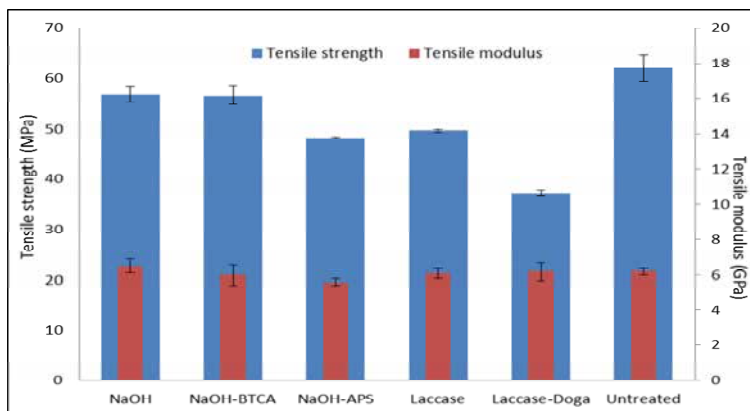


Figure 3: Tensile strength and modulus of flax/composites with treatments.

As seen in Figure 3, the performance of composites with 5% NaOH (type 1) and NaOH-BTCA (type 2) treatment (tensile strength of around 58 MPa) was comparable to the original composite (type T). All other treatments lowered the tensile strength of the composite. This strength reduction is possibly related to the loss of intra-matrix (e.g. hemicellulose) between micro-fibrils during surface treatments. From the distribution of tensile strength in Figure 3, the NaOH-APS, laccase and LG-D treated composites showed much smaller variation than the neat fibre composites. The tensile properties of the composites hence are more stable and consistent. In terms of the modulus, the NaOH-APS treated flax composites showed the smallest tensile modulus of 5.6 GPa, around 10% less than that for untreated composites (6.2 GPa). Singha and Rana (2012) have reported that the APS treatment will destroy packing of the cellulose chains to a certain extent and causes disorder in the crystalline pattern of the main polymeric backbone. Other surface treatment methods like NaOH, NaOH-BTCA, Laccase, and Laccase-Doga had little effect on the tensile modulus of fabricated composites. It indicates that these surface treatments only influence the re-arrangement of micro-fibrils by transferred stress towards the tension direction, after the initial linear stress-strain part. This may be due to the loss of intra-fibril matrix, making the extension of micro-fibrils more easily.

4 CONCLUSIONS

Five fibre pre-treatments were employed and expected to enhance the mechanical performances of flax/tannin composites. The roughness of the fibre surface clearly increased after the treatments through the SEM images. It may ideally benefit the fibre/matrix adhesion and the mechanical properties. However, the DMA results showed the broadened T_g peaks and complicated initial storage

modulus, while reduction of tensile strength was observed after some modifications. NaOH and NaOH-BTCA treated composites maintain the tensile properties. The two methods are more compatible with tannin system and offer good flax/tannin wettability. In addition, NaOH-APS, laccase and LG-D treatments result in more consistency of the tensile properties of the composites.

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NOVEL NANOCOMPOSITE AUTOMOTIVE TEMPERATURE SENSING TECHNOLOGY

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ABSTRACT

In recent years, automotive emissions legislation has been introduced and is rapidly becoming more stringent. With alternative vehicular propulsion methods far from becoming mainstream reality, leading automotive providers have intensified efforts in the direction of reducing the harmful footprint of their products. This is being accomplished via smaller, more optimally designed internal-combustion engines. A crucial means to that end is exhaust gas temperature monitoring and control. To enable such control, a mass-produced sensor, capable of operating reliably in the harsh automotive combustion environment, comprising a broad spectrum of high temperatures, severe shocks and a chemically aggressive ambient, has been used widely in the past decade, with performance demands growing constantly in line with advances in engine performance. This paper presents a technology overview of the potential of novel nano composite sensor design and manufacture using materials in an innovative way towards industrialising such a sensing solution. The presented sensor design implements the state-of-the-art in thick and thin film technology incorporating nano materials for improved strength, fabrication and performance properties.

Keywords: Thin Film Technology, Thick film technology, Exhaust Gas Temperature Sensing.

1 INTRODUCTION

Exhaust gas temperature has been measured since the earliest implementation of temperature measurement devices (Carstens, S., (2010)). Concerns for excessive temperatures from intake, through combustion to exhaust, meant a number of measurements were desired. Catalytic converters require a minimum temperature of 350°C to be effective and increasingly tougher emission regulations mean manufacturers want to measure the temperature in the catalyst, by inserting a linear temperature sensor diagonally across the converter, as soon as possible after cranking. Additionally, for fault condition monitoring, exhaust gas temperature sensors are able to detect localised hot spots inside the catalyst which enable detection of misfire. The temperature of exhaust gases increase rapidly under severe operating conditions such as continuous high load or insufficient octane rating offering invaluable information on current combustion behaviour.

The widespread onset of turbochargers to enable engine cubic capacity reduction while maintaining power has seen a dramatic increase in the requirement for high accuracy, fast response temperature sensing as excessive over-temperature exposure can be detrimental to low tolerance fit

turbine blades. The range of resistance has been evaluated and a time constant of two seconds is achievable (Jurgen, R.K., (1999)). There are also designs in which the sensing element is not completely covered by the housing but is perforated with holes to allow direct contact with the gas thus achieving minimal response times. The temperature can also be monitored at the exhaust manifold. If the sensor detects exhaust gas temperature above a certain limit extra fuel is inserted into the chamber to cool the engine.

The fundamental principle utilized in exhaust gas temperature sensing is the change in electrical resistance with temperature. Platinum is often the material of choice due to its stability towards the harsh operating environment, high temperatures (ambient up to and over 1000°C), relative chemical inertness and an almost linear (quadratic approximation) temperature- α -resistance function.

Platinum-chip temperature sensors can be manufactured using the latest thick and thin-film techniques, ordinarily in clean-room conditions. Unlike the wire-wound temperature sensors, the platinum layer in platinum-chip temperature sensors is applied to a ceramic substrate in a serpentine structure as shown in Figure 1. The electrical connection is made through special contact areas, onto which the connecting wires are bonded. A protective layer of dielectric is required to protect the platinum serpentine from external influences and also serves as insulation. The temperature at which platinum-chip temperature sensors can be used depends on their design, usually in the range from -70 to +650°C. To measure temperatures from 650°C to above 1000°C the basic design remains but sophisticated material science and manufacturing is required especially when such a sensor will be exposed to extreme thermal shocks and the harsh chemical environment synonymous with the combustion engine. Platinum-chip temperature sensors combine the favourable properties of a platinum sensor, such as interchange-ability, long-term stability, reproducibility and wide temperature measurement range, with the advantages of large-scale production. Additionally, owing to the small dimensions and low mass, very fast response times are achieved (JUMO GMBH & CO. KG, (1999)). A typical platinum-ceramic chip design temperature sensor is shown in Figure 1 below taken from (McGhee, J. (2005)).

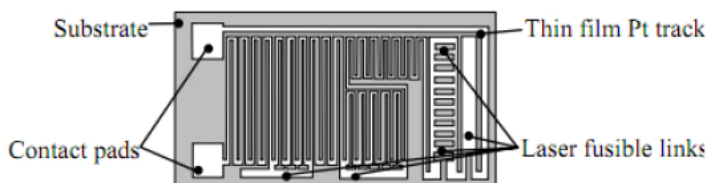


Figure 1: Platinum-chip temperature sensor

2 NANOCOMPOSITE STRUCTURED TEMPERATURE SENSOR

This paper presents a technology overview of state-of-the-art in novel production for high volume manufacture for a composite sensor designed to exploit nanostructured materials for an optimum balance of materials use and sensor performance. The presented sensor design implements the state-of-the-art in thick and thin film technology incorporating nanostructured composite materials for improved strength, fabrication and performance properties.

It is critical to address demands from an automotive sector creating more challenging environments with ever-growing ambient temperatures of 750oC – 1000oC with thermal and mechanical shock for a significant period of time, striving for more economical engine power output.

This nanocomposite sensor design will enable automotive manufacturers to;

- Implement further pollution control
- Meet forthcoming CO₂ and other emission targets

This nanocomposite sensor design will enable production to meet demands through;

- Manufacturing optimisation
- Improved quality and reduced cost

The challenges presented above are being met with novel nanocomposite application through thick and thin film technology for the production of closed and open housing sensing product applications, fully integrated with current, established high volume manufacturing process. Terms “thick and “thin” film do not relate to the thickness of the film but more to the method of deposition (Altenburg H et al., (2002)). Thick films are made by low-priced processes such as doctor blading, screen-printing, or spraying methods whereas thin films are usually produced from a source material (target) to a substrate in a controlled environment (Singh Nalwa., (2002)). The current commercial sensing element is encased in a perforated housing, for reduced response time, which can be inserted into any section of the exhaust gas system. Figure 2 below presents a cross section of the housing element and the current and advanced composite design. Items marked with a 1 define thick film technology and 2 represents thin film technology.

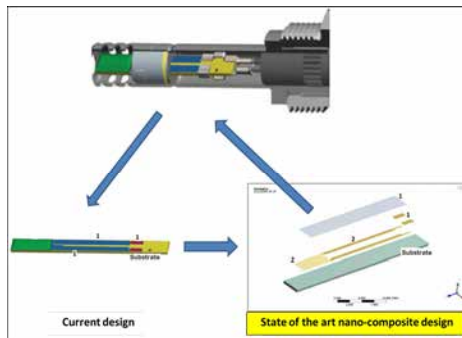


Figure 2: Advancement from current design using thin and thick film technology

3 NANOSTRUCTURED COMPOSITE BY ATOMIC DEPOSITION

Advantages of thin film technology to the present application are numerous including miniaturisation, lower material consumption and a higher automation potential, all leading to prospects of increasing quality and managing cost in a mass-production environment. The fabrication and consequential usage of atomic deposition from a target material is simpler than originally used paste formulation.

The selected technology for thin films described here is from Plasma Quest Ltd (Plasma Quest Technology). The patented high target utilisation sputtering (HiTUS) process is based on the remote generation of high density plasma. The plasma is generated in a side chamber opening into the main process chamber, containing the target and the substrate to be coated. A schematic of the system is given in Figure 3.

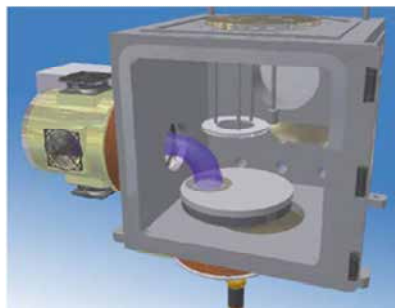


Figure 3: High density plasma deposition system from Plasma Quest Ltd.

High magnification SEM analysis presents the microstructure of plasma deposited nano crystalline structure which is closely packed and shows no signs of porosity.

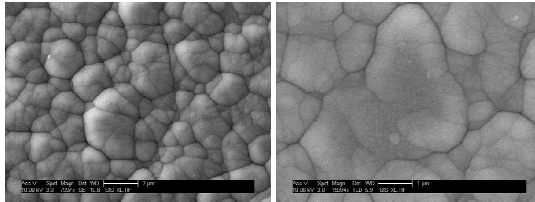


Figure 4: SEM imaging of plasma deposited nano structured layer

Plasma deposition gives additional degrees of freedom to the growth process and allows new processes and structures to be developed. It is also possible to implement multi-target and multi-substrates devices in the process chamber, allowing semi-continuous batch series and multi-layer deposition. High Target Utilisation Sputtering, HiTUS uses in excess of 90% of the target compared to less than 40% for magnetron sputtering due to the elimination of the racetrack, generated by preferential material erosion of the target, as demonstrated in Figure 5 below.

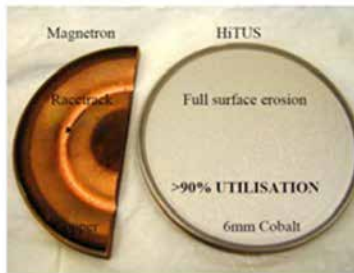


Figure 5: Magnetron v HiTUS target wear

Deposited film stress is controllable; from compressive to tensile (PlasmaQuest). Properties, such as refractive index and resistivity are close to bulk values. A cross section image of a specimen produced to date is presented in Figure 6.

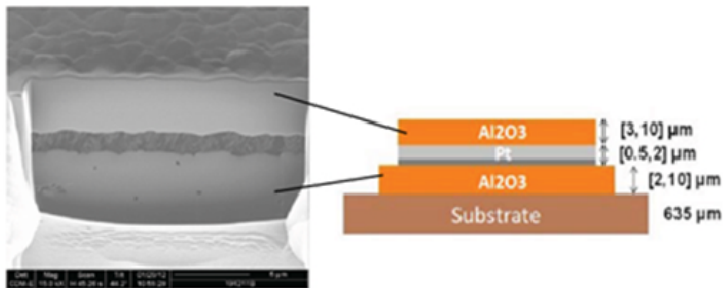


Figure 6: Focused ion beam analysis of a nanostructured composite prototype sensor

4 NANOSTRUCTURED COMPOSITES FOR SCREEN PRINTING

Once deposited on a substrate, the thermistor requires a suitable packaging that will restrict platinum metal contamination, evaporation, mechanical damage and other factors that can alter negatively the electrical properties' and stability of the thermistor layer. Typical materials of choice are alumina, magnesia, silica, a suitable high-temperature glass formulation, or variants of combinations of the above. This protective layer has to represent an efficient barrier to chemical contamination and be of a suitable coefficient of thermal expansion, in order to minimise thermally induced stresses, and able to retain its properties in time, under the operating conditions of the sensor.

Screen printing is an effective method of depositing relatively thick layers of material, using a specialised thick film paste, quickly and cost effectively. The quality and performance of the final layer is predetermined by the printed structure, which itself is predetermined by the formulated thick film paste. High quality, well controlled material science is required to enable the final layer to function in service through extreme thermal shocks, continuous contamination and mechanical damage for a significant time. To fulfil this stringent requirements the final layer must be dense with no through porosity obtained only through optimum paste formulation.

A dense layer can be achieved by producing a paste with very high solids loading (>80%). A ternary powder system has been chosen to achieve this. To enable manufacturing under current production conditions the screen printed paste must sinter at temperatures much below the theoretical. This is not possible with a pure alpha-alumina powder system as densification will not occur until 1600°C. Various additives can be added to alumina to promote densification; MgO, TiO₂, SiO₂, Fe₂O₃ resulting in a nanostructured alumina composite. Work is on-going regarding dopants with commercially available aluminum oxide powders or as a metal precursor mixed with powders, hydrolysed, washed, dried and calcined, following sol-gel routes (Taylor, A. et al (1998)).

The paste must be screen printable therefore the ideal polymer and solvent constituents along with appropriate ratios must be chosen through literature and experimentation. Such high powder loading of the paste leaves less space for binder and solvent resulting in a more complex selection process but also less shrinkage when these components are removed during pyrolysis. The ratios and preparation of the constituents directly influences the resulting material properties and is widely thought of as a mainly empirical process.

5 CONCLUSIONS AND FUTURE OF NOVEL NANOCOMPOSITE AUTOMOTIVE TEMPERATURE SENSING TECHNOLOGY

The combustion engine is the predominant form of automotive power and will remain to be for the foreseeable future. It is a common belief that it must become more efficient for greener motoring for regulatory, planet sustainability and economic purposes.

This paper has presented a novel manufacturing process utilising atomic deposition of thin film platinum via plasma generated sputtering encapsulated in a nanocomposite, application specific, screen printed alumina paste to produce a novel nanocomposite sensor to meet the stringent demands of low-cost, high-volume manufacture required by the automotive industry immersed in a pressured environment requiring continuous reduction of exhaust gas emissions and fuel usage.

Sales in developed markets such as the U.S., Western Europe, and Japan fell nearly by 9%, 2%, and 4% respectively per year from 2004 to 2009, while emerging markets such as Brazil, China, and India grew by almost 14%, 26%, and 12% respectively per year during the same period. This has made emerging markets a better market for automotive temperature sensors as the automotive temperature sensor market is highly dependent on automobile production (marketsandmarkets.com (2011)).

Governments play a significant role in the growth of automotive temperature sensing as environmental regulations such as Euro 5, Euro 6 in Europe aim to limit pollution caused by road vehicles. These regulations require more complex and additional sensing systems. This results in more electronic content in automobiles. The revenue for the automotive sensor market is expected to grow from \$14.5 billion in 2011 to \$20.70 billion in 2016 at a CAGR of 7.4% from 2011 to 2016. Emission rules worldwide and fuel economy standards will increase the demand for exhaust-gas temperature sensors. Mandates are expected to come into effect in South Korea in 2012 and this is going to impact

more than a million passenger cars in the country by 2014. Japan and China are expected to emulate these models in the near future and help sustain the growth and further development of semiconductor-based automotive sensors (Taylor, A. et al., (1998)).

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A GENETIC ALGORITHM APPROACH TO DESIGNING AND MODELLING OF A MULTI-FUNCTIONAL FRACTAL MANUFACTURING LAYOUT

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ABSTRACT

A dynamic and optimal shop floor design, modelling and implementation is key to achieving successful Fractal Manufacturing System (FrMS). To build adaptive and fault-tolerant fractal layout, attention is paid to issues of shop floor planning, function layout, determination of capacity level, cell composition planning and flow distances of products. A full fledged FrMS. layout is multi-functional and is capable of producing a variety of products with minimal reconfiguration. This paper is part and a progression of an on-going project whereby Genetic Algorithm (GA) is adopted to design and model a flexible and multi-functional FrMS floor layout. GA is used in the project for modeling and simulation. The design implementation is done using MATLAB. The result is a fault tolerant configuration that self-regulates and adapts to unpredictable changes in the manufacturing environment arising from lead time reduction pressure, inventories, product customization and other challenges of a dynamic and volatile operational environment.

Keywords: fractal manufacturing layout, production planning, genetic algorithm.

1 INTRODUCTION

A dynamic and optimal shop floor design, modelling and implementation is key to achieving a successful FrMS. A full fledged FrMS. layout is conceptually capable of producing a variety of products with minimal reconfiguration. The conceptual fractal shop floor builds up from individual cells called fractals and is capable of producing a variety of products (Venkatadri *et al.* 1997; Montreuil *et al.*, 1999). The fractal layout is an extension of the cellular layout (Askin *et al.* 1999) and in fact, each fractal cell is a multi-functional mini shop (Venkatadri *et al.*, 1997) since it could produce most of the product types routed to it and have layout specification that produce varied products. A design and simulation of the model of shop floor layout for FrMS is presented in this paper paying attention to determination of capacity level and cell composition using GA approach. The procedure is based on an iterative algorithm, implemented using MATLAB and used to calculate material travelling distances for each fractal cell and this continuously optimizes the layout, flow assignment and improves the overall performance of these parameters to create maximum space utilization. The rest of the paper is as follows; section two is on FrMS layout, section three presented FrMS layout design. Section four implemented the GA approach, while section five discusses output results and the paper is finally concluded in section six.

2 FRACTAL MANUFACTURING LAYOUT

The fractal workstation layout is created to minimize the capacity requirements and material travelling distances (Saad and Lassila 2004). The layout design concerns the arrangement of physical production resources within the production facility (Chase and Aquilano 1992) and the planning of which involves the determination and allocation of the available space to a given number of resources (Azadivar and Wang 2000) and emphasizes minimization of flow distances in order to improve product flow and general layout performance (Montreuil *et al.*, 1999). This involves various steps; capacity planning, fractal cell creation, flow assignment and cell/ global layout (Venkatadri *et al.* 1997). These significantly affect shop floor control, equipment utilization, materials handling, materials management, and worker productivity (Co and Araar 1988). The manner and nature of the flow of materials through the facility is of crucial importance (Wild 1993).

2.1 Multi-functionality of fractal cell

The fractal cell is a set of neighboring workstations and is the basic unit in the fractal layout system (Saad and Lassila 2004; Venkatadri *et al.* 1997 & Montreuil *et al.* 1999). It should generate the manufacturing procedures and routes, production scheduling, material requirement planning etc. (Prasada, K.V., 2005). All fractal cells have roughly the same composition of machines and are capable of processing most of the products routed to them. This capability of producing a variety of products with minimal reconfiguration is termed multi-functionality and directly impacts on the flexibility of the system. The most important objectives of the fractal layout are how to minimize the movement and handling of materials, maximize the capacity utilization (Wild 1993) and ensure a smooth work flow (Chase and Aquilano 1992). Shop floor control manages the work in process (Figure 1) and production orders through the various workstations (Prasada, K.V., 2005).

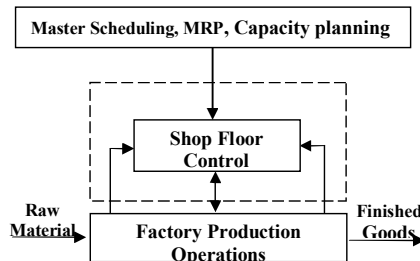


Figure 1: Relationship of Shop floor control in Production System (Prasada, K.V., 2005).

3 THE PROPOSED FRACTAL MANUFACTURING LAYOUT DESIGN

As a guide, the initial fractal manufacturing layout adopted for this study is the cellular manufacturing systems configuration proposed by (Co and Araar 1988) (Figure 2). This layout is re-designed and reconfigured from its initial cellular manufacturing layout using the GA optimization technique. Limitations of the cellular manufacturing layout include inflexibility due to a fixed set of part families and limited allowance for inter-cell flows. It also contains different types of machines which increases the product inter-cell and intra-cell travelling distances. This design is modified and illustrates with 15 distinct product types and 10 types of machine in the initial cellular layout. A total of 64 workstations are located in the factory. But, each group of cell contains uncertain number of machines. In this study, the GA approach lets us represent the entire group layout proposed by (Co and Araar 1988), (Figure 2) as chromosomes. MATLAB made the representation of the machines in each cell easier. Cell1 is represented as (1 5 2 6; 7 4 3 8; 9 10 3 5; 2 10 8 6; 1 5 9 10) in MATLAB codes. Cell4 is coded as (3 9 2 8; NaN NaN NaN 5) (where NaN means Not-a-Number in computing). Cell1 and

Cell4 are combined using crossover operations. Cell1 is re-generated and it becomes one of the output cells for fractal manufacturing layout.

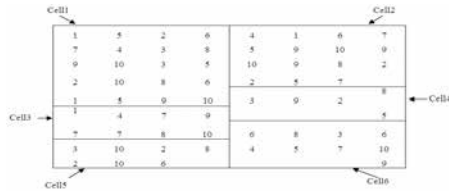


Figure 2: Modified group layout from (Co and Araar 1988)

All fractal cells are similar and contain roughly the same composition of machines. Similarity of fractal cells in terms of machine types and quantities enable high efficiency in controlling shop floor, high operational flexibility and high flexibility for factory expansion. The design of fractal layout (Figure 3) contains three cells. This choice leads to a cell population of 10 workstations, which is within tractable standards of 5 to 15 machines in each fractal cell. It is not necessary to limit the number of workstations to 30 machines in this case (Venkatadri *et al.*, 1997). But, by adding few more workstations congestion could be alleviated and flow efficiency could further be improved.

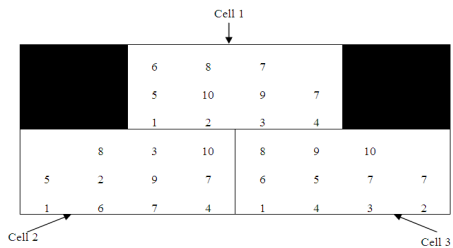


Figure 3: Fractal Manufacturing layout (Co and Araar 1988)

4 IMPLEMENTING THE GENETIC ALGORITHM APPROACH

An iterative algorithm is implemented to optimize the layout and flow assignment. The layout of each cell is refined while the replicates are re-applied until the heuristic procedures could not find a better solution. The cells are continually iterated to obtain the optimal flow assignment and hence achieve the optimum fractal layout (Montreuil *et al.*, 1999). The GA procedures - selection, crossover, row inverting mutation, column inverting mutation, and deleting mutation are embedded in the iterative procedure in order to generate the optimal material travelling distances. Hence the desired workstation layout that minimizes the material travelling distances and capacity requirements for product demand and mix is created. Each optimal fractal cell is selected based on the flow distance score. Thus, optimum fractal manufacturing layout is created by combining the three optimal fractal cells. The illustrations of the GA steps are presented, showing the first iteration of the fractal cell 1. Initial cellular layout is assumed to contain 6 cells. Fractal cell1 is generated by combining cell 1 and cell 4 by crossover operation. Cell 1 is shown as parent1 and cell 4 is illustrated as parent2 in MATLAB program codes. Chromosomes for each Parent are represented by the various kinds of genes. The genes are represented by the number 1 to 10 that signify that Machine1 to Machine10 are used. Parent1 is represented as (1 5 2 6; 7 4 3 8; 9 10 3 5; 2 10 8 6; 1 5 9 10), illustrated in 5 rows and 4 columns. Parent2, contains 2 rows and 4 columns as (3 9 2 8; NaN NaN NaN 5). The chromosome for each parent is represented in rows. This means that the chromosomes for Parent1 are (1 5 2 6), (7 4 3 8), (9 10 3 5) and so on. One of the chromosomes from Parent1 is chosen randomly. For instance, the first row chromosome for Parent1 has been selected for the crossover function. On the other hand, the 1st row chromosome for Parent2 also is selected to be combined with the chromosome of Parent1 as

shown in (Figure 4). The continuous selection of the chromosomes for Parent1 and Parent2 generated 10 different Offspring after the crossover operation (Figure 4). Two Off-springs are generated from each iteration of the crossover. The Offspring1 that is created from selection and crossover with 5 chromosomes are selected for the upcoming mutation. Offspring2 is not been used because there are only 3 chromosome lesser than in Offspring1. Inverting mutation takes place after the crossover. The Offspring that is generated in the previous crossover is used as the Parent again in this inverting mutation operation. Initially, a cutting point is randomly introduced anywhere along the last row of the Parent. The cutting point indicates the row of the chromosomes for the inverting mutation. The last row of the chromosome is being mutated to the initial row based on the programming code “cireshift” - (mathscript function). For each offspring that is generated, three column inverting mutations takes place. For column inverting mutation, chromosome is represented column by column. The cutting point is set in the last column of the chromosome. The column-based chromosome is mutated and shifted from the last column to the first column.

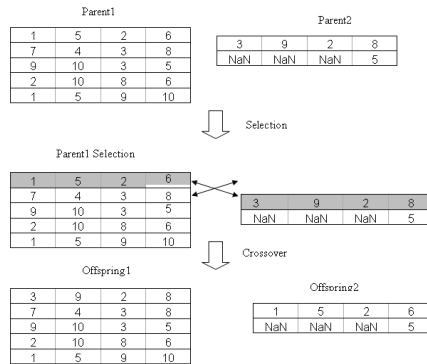


Figure 4: Selection and Crossover

After this, the Parent is replicated by shifting its chromosomes in columns as shown in (Figure 5). For each Parent that is obtained from the previous mutation step, the entire inverting mutation is expected to replicate 12 times.

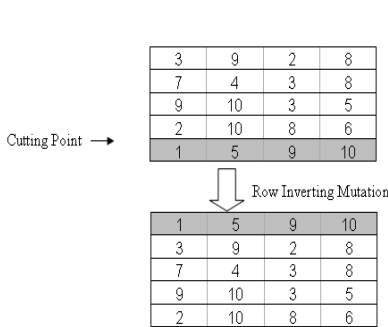


Figure 5: Row Inverting Mutation

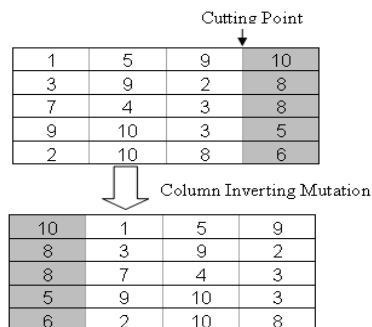


Figure 6: Column Inverting Mutation

After inverting mutation (Figure 6), the Child is generated and transformed to be the Parent again for deleting mutation as shown in (Figure 7). On completion of the previous mutation, the process of deleting mutation is simplified by just deleting the last two rows of the five chromosomes in the Child.

10	1	5	9
8	3	9	2
8	7	4	3
5	9	10	3
6	2	10	8

↓ Deleting Mutation

10	1	5	9
8	3	9	2
8	7	4	3

Figure 7: Deleting Mutation

10	1	5	9
8	3	9	2
8	7	4	3

Replacement

10	1	5	9
8	3	6	2
NaN	7	4	NaN

Figure 8: Replacement

Replacement is the last step in the process of generating fractal cell layout as shown in (Figure 8). Each fractal cell requires 10 machines where no duplicated machines or missing machines are allowed. The program searches the missing machines which is machine6. Thus, machine6 replaces one of the duplicated machines. The fractal cell layout that is generated after Replacement can be represented as (10 1 5 9; 8 3 6 2; NaN 7 4 NaN). Materials are moved into the cell through Pick-up Points and moved out from the cell through Delivery Points as shown in (Figure 9). The Pick-up Point is at (1, 1) while the delivery Point is at (3, 4). Before the materials are processed in machine1, they have to be carried into the fractal cell through the Pick-up Point. After processing within the fractal cells, the final product1 gets delivered to the shipping department through Delivery Point as shown in (Figure 9).

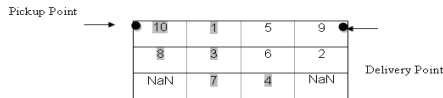


Figure 9: Material Routing sequence for Product1

Then the flow distance score is calculated based on the mathematical solution in MATLAB which is represented as:

$$\text{Distance} = \text{abs}(\text{buffer1}(1)-\text{buffer2}(1))+\text{abs}(\text{buffer1}(2)-\text{buffer2}(2)) \dots\dots\dots(1)$$

abs is abbreviation of absolute. The absolute value allows the distance to the left (negative value) and distance to the right (positive value) to be counted into the total distance. Buffer1 and buffer2 are the matrices of data that are being stored in temporary memory.

5 OUTPUT RESULTS AND DISCUSSIONS

The computational result of product travelling distances within the fractal cells indicates the flow scores of fractal layout. Flow score is computed and represented as the product travelling distances. The GA search for an optimal solution yielded results from 100 iterations and the output is converted into the final fractal cell layout representing the fractal manufacturing layout. The material travelling distances for each of the three fractal cells are; Flow distance score for Cell 1 = 205; Flow distance score for Cell 2 = 217; Flow distance score for Cell 3 = 197. Overall flow distance score for the final fractal manufacturing layout through the proposed GA = 619 and this is shown in (Figure 10). Comparatively, the fractal layout according to (Venkatadri *et al.*1997) has machine requirements similar to our final layout requirements with the following flow distances; Flow distance score for Cell 1 = 251; Flow distance score for Cell 2 = 252; Flow distance score for Cell 3 = 257. Overall flow distance score for Final Fractal Layout according to (Venkatadri *et al.*1997) is = 760 and that is shown in (Figure 11). This shows that the flow distance score obtained from the proposed GA approach

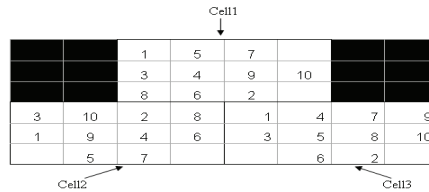


Figure 10: Final Fractal Manufacturing Layout A

is lesser at 619 than that of (Venkatadri *et al.*1997).

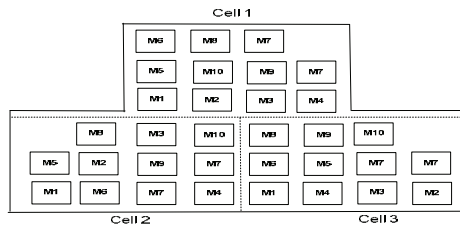


Figure 11: Fractal cell layout according to (Venkatadri et al.1997)

6 CONCLUSION

The GA approach was used in the design of the FrMS shop floor layout. It was used to search for optimal fractal cell layout for efficient and effective material/ product movements within the shop floor. The decision of how to distribute/assign products to cells as evenly as possible to aid responsiveness to uncertainties and easy control of resources was important in the design, implementation and final outcome of the experimentation. MATLAB managed the scenario quite well and handled the mathematical formulations, swapping and deleting matrices etc. quite efficiently. Overall, the computational results indicated that unrestricted product flows offer the best flow scores in a fractal layout.

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SURROGATE MODELLING FOR RELIABILITY ASSESSMENT OF CUTTING TOOLS

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ABSTRACT

Currently, cutting tool life for machining operations is correlated to process parameters through the widely applied Taylor functions. The latter are valuable expressions in established practice however their generalised nature does not allow accurate prediction of the tool's service life or optimization of the manufacturing process due to effects of uncertainties in various input variables. These variables should be treated in a stochastic way in order to avoid employment of safety factors for quantification of uncertainty. This paper documents a procedure that allows derivation of analytical expressions for cutting tools performance employing advanced approximation methods and concepts of reliability analysis. Due to the complexity of manufacturing processes surrogate modelling (SM) methods are applied, starting from a few sample points obtained through lab or soft experiments and extending them to models able to predict/estimate the values of control values/indicators as a function of the key design variables, often referred to as limit states.

Keywords: Kriging, surrogate modelling, manufacturing tool reliability.

1 INTRODUCTION

Performance degradation of cutting tools is an aspect of major importance towards optimization of manufacturing processes. Flank and nose wear, crater formation, and built-up edge are only a few unwanted tool wear mechanisms that can have a significant impact on the surface finish of manufactured components yielding a need for costly reworks due to waste of raw material or classification as un-acceptable. The latter case may lead to production delays due to the additional work introduced and hence it has been established as current practice to replace tools even though the still retain 20-50% of extra service life (Wiklund 1998).

Hard and brittle materials, which perform in a way that a local defect propagates rapidly and hence with sever effects are characterized as "difficult to machine" and therefore demand an even greater understanding of the conditions of cutting tools which illustrate high wear rates on both the flank and the face of the tool.

Although fabrication of cutting tools follows processes of high quality, their performance (also considering the interaction with the cutting surface) is characterized by stochasticity, constituting deterministic approaches to prediction as insufficient. To this extend and considering that tooling cost in flexible manufacturing accounts for a quarter of the total machining costs (Shakarov et al. 1990); more systematic methods should be employed in order to accurately quantify the effect of uncertainties. Concepts of structural reliability has widely been applied in cases of critical systems in aspects of frequency or consequence of failure; nuclear (Ellingwood 1998), aviation (Liu and Moses 1994), offshore (Kam 1988), and critical infrastructure (Micic et al. 1990) to name a few. Therefore the applicability of such methods in estimating cutting tool reliability is considered in the present paper.

This paper aims to adopt such practices for the probabilistic prediction of the cutting tool fatigue life starting from a limited number of experimental data, and following by using surrogate modelling

as an approximation methods construct an implicit expression linking flank wear to feed rates and cutting speeds over time. The latter can then be combined to existing reliability analysis methods expressing the probability of failure (or reliability) of a cutting tool under stochastic inputs.

2 PERFORMANCE OF CUTTING TOOLS

Performance degradation of cutting tools is characterized by a number of different wear modes and mechanics, such as flank wear and crater development. The various wear mechanisms essentially depend on the cutting conditions and on the tool and part materials. A number of different types of wear mechanisms can be observed depending on the cutting conditions (figure 1). Typically tool failure modes are dictated by the following types of wear mechanisms (El Wardany and Elbestawi 1997):

- Gradual wear (flank and nose wear), observed at low feed, speed, and depth of cut
- For higher values of depth of cut, the dominant failure mechanism is the depth of cut notch on the tool rake and flank faces
- For high cutting speeds and relatively high feed speeds, catastrophic failure due to tool breakage occurs. The time and severity of tool breakage depends on the speed.
- In finishing processes, depth of cut notches and secondary grooves are the causes of tool failure since the former causes chipping of the tool and the latter spoils the quality of the workpiece surface.

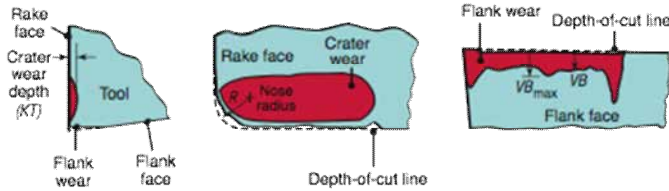


Figure 1: Wear characteristics (Kalpakjian and Schmid, 2008)

They can generate different statistical distributions of the operating time to failure such as the normal, the log-normal or the Weibull distributions. To evaluate the reliability of cutting tools in both variable and constant feed machining process, a mathematical model based on the theory of probability is necessary. This stochastic model is related to the random variable associated with the operating time to failure of the cutting tool.

3 CONCEPTS OF STRUCTURAL RELIABILITY

Reliability is defined as “the ability of a system to fulfil its design functions under designated operating and environmental conditions for a specified period of time”. The probability of failure can be seen as the probability for which a limit state for a system is exceeded. This can be expressed for a multi-variable system $X = \{X_1, X_2, X_3, \dots, X_k\}$ using a Limit State Function as:

$$g(X) = L(X) - V(X) \quad (1)$$

Where L is the limit and V the actual value of the limited variable.

According to the definition of the Limit State Function given above, the probability of failure can be mathematically defined as the probability for the limit state condition to be unsatisfied: $P_f = P[g(X) < 0]$. Hence the probability of failure can be rewritten as:

$$P_f = \int_{-\infty}^0 f_g dg = \int_{g(X) < 0} f_g dg \quad (2)$$

The solution of this integral is in most cases very difficult, if not impossible, to be analytically derived hence approximation methods are often employed characterised by different computational requirements and accuracy. First and Second Order Reliability Methods (FORM/SORM) employ second order Taylor expansions formulating easy to model algorithms for computation of P_f (Choi et al., 2007).

Further to analytical, stochastic methods such as Monte Carlo simulations are widely used due to the fact that they do not require much knowledge and statistical understanding of the problem. The algorithm is easy to implement and consists of launching several times the deterministic model with different inputs and checking each time if one or more thresholds are exceeded or not. Disadvantage of the method is that it is not suitable for low probabilities of failure as it becomes computationally demanding.

4 RELIABILITY ANALYSIS OF CUTTING TOOL LIFE USING SURROGATE MODELING TECHNIQUES

4.1 Approximation Methods

Complexity of engineering problems often demands reduction of system through appropriate approximations, formulating expressions that explicitly represent the relationship between inputs and outputs. Available techniques distinguish Response Surface (RSM) and Surrogate Modelling methods (SM). Both methods start from a limited number of $\{Y_i, X_i\}$ points, the first category attempting to find an interpolating fit through those points (best fit) while the second one, through more numerically intensive procedures build models that can accurately reproduce the initial points (passing through). In the RSM, polynomial regression techniques (MPR) and generalised linear models (GLM) can be identified while in SM techniques such as kriging and radial basis functions (RBF) (Khuri 2001). Approximating the system under analysis using such expressions facilitates analysis allowing both optimization and reliability analysis since objective and Limit State functions can be approximated with such techniques. Response surface methods, in particular SRSM, have already been employed successfully both in optimization and reliability analysis (Queipo et al. 2005), as well as kriging (Forrester et al., 2006).

4.2 Surrogate Modelling - Kriging

Kriging is an evolution of Gaussian radial basis functions using the following basis function to approximate the original one:

$$\text{corr}[Y(x^{(i)}), Y(x^{(j)})] = e^{-\left(\frac{\sum_{k=1}^K \theta_k |x_j^{(k)} - x_j^{(i)}|^2}{p_j}\right)} \quad (3)$$

Which represents the correlation between two sample points. The two parameters that differentiate this basis function from the Gaussian radial basis one are the smoothness coefficient p_j that represents how fast the function is and how quickly tends to infinite and zero and θ_j , which stands for the ‘activity or width parameter’ and gives information about how much the output is affected by the corresponding input. The prediction at a new point is assumed to follow the same correlation. Finding the parameters values is a procedure done maximizing the likelihood of the sample set which is partially achieved through analytical differentiation and partially by direct search (e.g. genetic algorithms, simulated annealing etc). The predictor is expressed as:

$$y^*(x) = \hat{\mu} + \psi^T \Psi^{-1} (y - 1\hat{\mu}) \quad (4)$$

Where ψ is the correlation vector between the samples and the prediction point, Ψ is the correlation matrix, $\hat{\mu}$ the MLE estimate of the mean of the sample responses and y the sample responses.

Having formulated the above expression, FORM is employed to quantify probability of failure through reliability index, through a localised search of the optimum design point to the design domain. In actual applications the limit state is, mostly represented by a second order polynomial in k variables. Kriging parameters obtained through kriging approximations performed on the reference

system can be used to directly work out the limit state expressing through the kriging predictor. What can be obtained from second term of the predictor is a single value that represents the deviation from the mean value $\hat{\mu}$. In the expression of this matrix multiplication one part of the formula dependent on the new prediction point, which is Ψ^T and a second part independent from this, $\mathcal{G} = \Psi^{-1}(\mathbf{y} - \mathbf{1}\hat{\mu})$ can be distinguished. $\mathcal{G}$ is a $n \times 1$ matrix where each line can be expressed as (Casali et al. 2012):

$$\mathcal{G}(i, 1) = \Psi^{-1}(i, 1)(y_1 - \hat{\mu}) + \Psi^{-1}(i, 2)(y_2 - \hat{\mu}) + \dots + \Psi^{-1}(i, n)(y_n - \hat{\mu}) \quad (5)$$

The multiplication $\Psi^T \mathcal{G}$ can also be expressed as

$$\Psi^T \mathcal{G} = \Psi^T(1, 1)\mathcal{G}(1, 1) + \Psi^T(1, 2)\mathcal{G}(2, 1) + \dots + \Psi^T(1, n)\mathcal{G}(n, 1) \quad (6)$$

Where, $\Psi^T(1, i) = e^{-\frac{1}{2}(\theta_1|x_{i,1}-x_1|^2 + \dots + \theta_n|x_{i,n}-x_n|^2)}$ and stands for the expression of the Limit State. The relevant algorithm is shown in Figure 2.

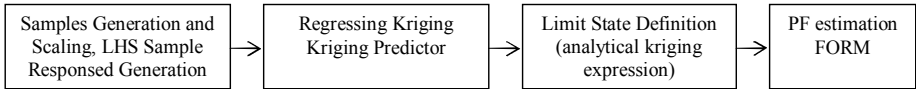


Figure 2: Analytical Kriging - FORM algorithm.

5 ILLUSTRATIVE EXAMPLE

In order to apply and validate the proposed method for tool wear reliability calculation, dry cutting tests were carried out on a high speed CNC turning machine tool. Within the present paper, the basic wear mechanism considered is the flank wear. It has been experimentally identified as the most dominant mode of wear and is a function of cutting conditions (cutting speed V_c , feed rate f and cutting time t), workpiece and cutting tool material, kind and type of coolant, etc.

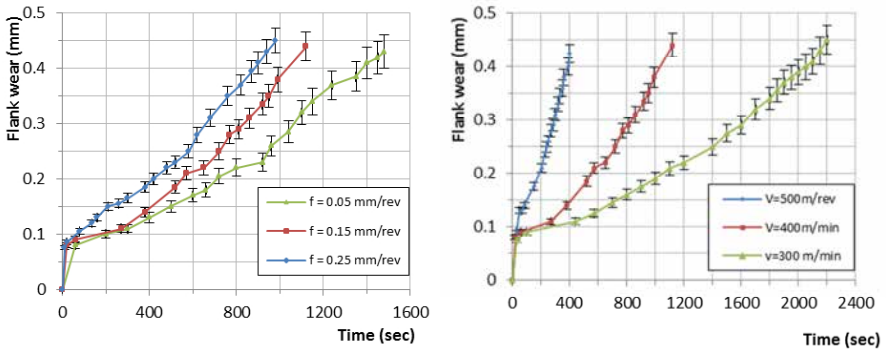


Figure 3: Tool flank wear (left) for different feed rates with $V_c = 400$ m/min and (right) for different cutting speeds with $f = 0.15$ mm/rev. In both cases cutting depth is $a_c = 0.8$ mm)

The workpiece material was C55 (EN10083-2) high carbon steel, whereas the cutting tool inserts used were made of tungsten carbide (ISO TNMG 160408SG). The flank wear V_B was measured periodically during the machining processes using an optical microscope. For each measurement, five sample measurements were taken. The wear flank value reported is the average value of these five measurements. For the present study, two process variables were considered, the feed rate and the

cutting speed. Feed speed values selected were 0.05, 0.15 and 0.25 mm/rev. Cutting speed values selected were 300, 400 and 500 m/min that resemble high speed machining process. In all cases the depth of cut was fixed at 0.8 mm. Figure 3 present the measured flank wear for different feed rate and cutting tool speed.

For the estimation of the reliability of the cutting tools, it was assumed that the tool wear distribution can be represented using a normal distribution. This is in agreement with Hitomi et al. (1979) and Wager and Barash (1971) who have observed that the cutting tool life can be represented by the statistical normal distribution. The tool life criterion (limit state definition) was set to be 0.3 mm.

Following the analysis outlined in section 4, the reliability and probability of failure for the cutting tools were estimated. In Figure 4, typical analysis results are presented for a specific cutting setup. The failure probability curve is the probability that flank wear will exceed the critical value subject to the stochastic variables of cutting speed and feed ratio with given statistical parameters at each time step. The effect of feed rate on tool wear failure probability is not so significant compared to cutting speed. It can be seen that tool wear reliability improves with decreasing of feed rate. With regards the cutting speed, as it decreases, the probability of failure falls, which subsequently results in cutting tool reliability remaining higher for longer times. This is in agreement to the authors findings using the combination of Response Surface modelling to Mode Carlo simulations and First Order Reliability Methods (Salonitis and Kolios, 2013).

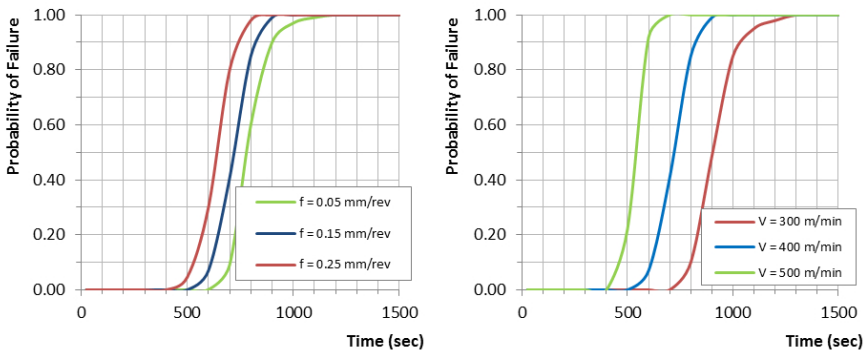


Figure 4: Probability of failure (left) for different feed rates with $V_c = 400$ m/min and (right) for different cutting speeds with $f = 0.15$ mm/rev. In both cases cutting depth is $a_c = 0.8$ mm)

6 CONCLUSIONS

This paper has documented a methodology for the efficient reliability assessment of cutting tool wear based on surrogate modelling (SM) methods, and more specifically kriging, for the estimation of reliability indices. Application of the method in a cutting tool wear with indicative statistical values has illustrated its efficiency and simplicity in implementation since each step can be executed individually.

The methodology employed herein can be extended to take into account more than two variables (cutting speed V_c and feed rate f in the present paper) increasing the number of variables stochastically modelled. These, together with consideration of more realistic values for the stochastic modelling of key variables, are currently studied by the authors of this paper.

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ADVANCED AUTOMATED FIBRE PLACEMENT

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ABSTRACT

The further increase of production rates while maintaining or improving quality and lower costs demand the development of new manufacturing solutions. For this purpose, within the project GroFi® the German Aerospace Center (DLR) develops a new plant, processes and sensor systems that enable a productive, cost-reducing manufacturing with an increase in quality of large-scale composite structures. The plant concept is a novel robot-based multi-head fibre placement facility, that coordinates its up to 8 layup units working on one or more components simultaneously. For the coordination of these layup units a closed CAD-CAM simulation was developed, that generates a time and / or cost-effective manufacturing process. To increase quality and productivity additionally, a comprehensive sensor system has been developed. This development of the DLR in the field of an advanced automated fibre placement technology serves the requirements of the current aviation industry.

Keywords: Automated Fibre Placement Technology, Sensor System, CAD-CAM Simulation.

1 INTRODUCTION

Developing light structural components in the field of aerospace is at all times a fundamental aim. To increase fuel-efficiency the use of fibre reinforced plastics will be pushed more and more.

This demand of a holistic development in the fields of composites also adheres the German Aerospace Center (DLR) with the Institute of Composite Structures and Adaptive Systems which closed the interface between basic research and industrial application by the opening of the Center for Lightweight-Production-Technology (ZLP) in Stade and Augsburg in the year 2010.

To accommodate the requirements for productive and accurate production technologies especially for aeronautics, new plant concepts for the fibre placement technology have to be developed.

Therefore DLR developed in the project GroFi® (German acronym for production of extensive components in fibre placement technology) a new plant, sensor systems and simulation tools, which are represented in this manuscript.

2 STATE OF THE ART

Nowadays fibre placement machines are applied in high quality production processes especially in the field of large, low-curved aeronautical shell structures likewise fuselage sections or wings. With the utilization of pre-impregnated fibre material (prepreg) a high quality material is given. To prevent or minimize inaccuracies by the machines, the historical background of the major manufactures are high precision milling and grinding machines. This resulted in gantry and portal machines with high weights and dimensions.(Evans et al. 1989)(Krombholz et al. 2011)(Krombholz et al. 2012)

The requirements for a high quality layup are given in current design rules. Especially the geometric tolerances are complied with the use of portal or gantry machines with high stiffness. The utilization of smaller and more flexible robot units was introduced by (Ahrens 1998) for the first time. Actually robot units are implemented in closed-to-productions for the aeronautic branch. The robot units are optimized for a high repeat accuracy and comply the requirements by adapted process parameters.

In order to improve the productivity of fibre placement and tape laying facilities, the employment of multiple layup units is inevitable. In industries, e.g. in automotive applications, multi-robot plants are well situated. In most cases the production units operate in separated workspaces with a fixed task allocation. Due to a lack of flexibility and redundancy of those plants, in the last few years a lot of research studies the possibilities of coordinated and cooperating robots. (Papakostas et al. 2011)

The approach of those flexible multi-robot applications presents several challenges, e.g. an optimized and collision-free path planning. With respect to the communication architecture there are two basic approaches. On the one hand there are multi agent systems with a decentralized control and cooperating units. For the GroFi[®]-plant a second approach is chosen. Therefore a centralized controller, referred to as master controller, is used to coordinate all production units.

In the aeronautic branch an inspection is submitted to ensure a high layup quality. Currently a visual inspection is carried out by a specialist after the layup of one ply or sequence. The visual inspections investigates the plies or sequences regarding material failures, intolerable layup failures (gaps/overlaps, wrinkles, crimps, bridging) and foreign bodies. Randomly there are also extensive measurement tasks, that make a qualitative statement about failures.

A sensor-based process to control and monitor the layup quality in a fibre placement production isn't realized yet. In addition, there are quality monitoring sensors in production technologies for composite structures. However, mostly they are implemented to inspect textile preforms after draping processes. (Schmitt et al. 2009) (Schmitt et al. 2007) (Schmitt et al. 2008) Due to the poor accessibility during draping processes with optical measurement systems no inline quality control is possible. This inspection has to be done in a separate process step. An inline quality inspection that doesn't result additional process steps isn't realized yet.

In other robotic production branches there are implemented sensor-controlled processes for an online path correction, especially in the welding technology. (Bollig 2005)(Roebrock & Böhnke 2007)(Veryba et al. 2000)

Precision in automation systems is mainly defined through various factors. Vibration is one significant source that affects the precision. The source of excitation can be clustered into three different types: process-induced movements in case of path planning, environmental conditions likewise behaviour changes through varying temperature and controllability limits of the drive engines. A huge amount of great research studies this topic. (Economou et al. 2000) (Hu 2008) (Itoh & Yoshikawa 2003) In case of increasing demands of the production rate and the necessary part quality the vibrational behaviour of a plant becomes the most important property. Therefore, studying the proposed plant structure is a current research topic (Perner et al. 2012).

3 FIBRE PLACEMENT PLANT CONCEPT

The basis of the project GroFi[®] is a fibre placement research facility in Stade which was invented and co-developed by DLR. This research facility forms an ideal interface, where applied research and development can be tested at full-scale components.

Special attention is placed on the process requirements flexibility, productivity, efficiency, process stability and quality of the structural component.

The research facility comprises a mold bearing system, which supports tools with up to 20m length and 5.5m width. Around this double-sided tooling there is a rail system which is split into a production-loop and in parallel with this, a maintenance loop (see Figure 1 and Figure 2).

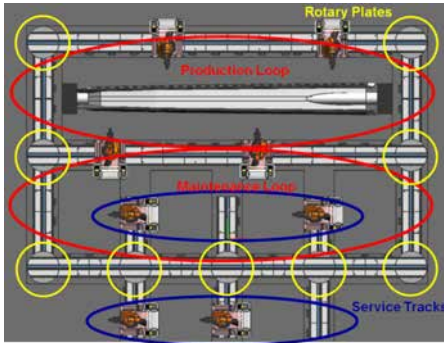


Figure 1: Top view of the GroFi[®]-plant with high-lighting production-loop, maintenance-loop, rotary plates and service tracks



Figure 2: Photo of the automated fibre placement plant GroFi[®] at the Center for Lightweight-Production-Technology

On this rail system up to 8 coordinated industrial robots can produce simultaneously. This robot based multi head layup facility is equipped with both, 16 x ¼ tow fibre placement and 150mm tape laying units. For the first time it's possible to use fibre placement and tape laying technology at the same time and for the same component. Every robot unit comprises a standard industrial robot (KUKA KR500) that is controlled by a Siemens 840D-sl NC. Due to the rotary plates and the loops there is no connection to the facility among the power. Everything else is provided on the platform (e.g. vacuum, compressed air) or wireless (e.g. control data, process data).

Due to the separated maintenance and production loop the productivity of the research facility can increase significantly as the result of missing or clearly reduced dead times. Furthermore, in case of a defected layup unit, or a layup unit which has to be discharged or maintained, it's possible to delegate tasks to other available units. That ensures a flexible and redundant process.

The innovative plant concept results in improvements of flexibility, productivity, efficiency and process stability and enables a fibre placement process for aeronautic composite structures with a mass throughput of up to 150kg/h.

To serve the purpose of an advanced automated fibre placement facility, DLR develops additional concepts in the field of CAD-CAM simulation and quality improving sensor systems.

4 CAD-CAM SIMULATION

Typically, current fibre placement and tape laying facilities consist of single layup units. In case of the GroFi[®]-plant up to 8 units produce simultaneously without delimitation of the individual working areas. For this reason the DLR develops a scheduling tool which can be used for both - offline programming and online rescheduling.

Figure 3 illustrates the CAD/CAM-chain of the GroFi[®]-plant based on the CAD-model of the target part. This model includes not only the geometry, but also the information about the complete plybook. Regarding a single unit process, the NC-data can be generated by feeding the information from the CAD-model to a separate software-tool, referred to as GroFi[®]-CAM. To make these NC-data accessible for a multi-head layup process, the GroFi[®]-CAM tool generates a separate NC-file for each course. If there is the possibility to process a course in different directions, one file for each direction is generated. This ensures a greater flexibility for the subsequent scheduling loop.

The logistic optimization is realized by the scheduling tool. This can be either done with respect to a minimum process time or minimum costs. The scheduling tool conflates the NC-files of the different courses with respect to real-time parameters likewise the material stock of the layup units or

their position into several working packages and assigns them to the available units. Simultaneously, a simulation tool carries out a collision analysis by reviewing the scheduling results.

Instead of considering the courses of each ply separately, the logistic optimization allots dependencies to the different courses. This is conducted by geometric conductions and defines the order, the course are considered for scheduling.

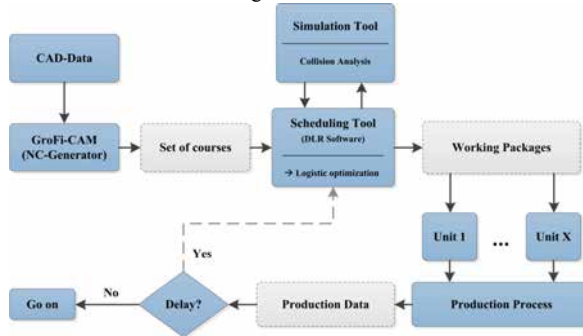


Figure 3: CAD/CAM-Chain

During the production process the layout-units return specific process parameters which are compared to the data of the offline programming. In case of a delay in the production process, e.g. based on a failure of a layout unit or material problems, an online rescheduling takes place. The algorithms of the offline programming are used for this purpose.

Due to the possibility of the online rescheduling and the consideration of course-dependencies, the CAD/CAM-system of the GroFi®-plant represents a flexible and redundant system which is able to compensate production delays automatically.

5 SENSOR CONCEPT

To precise the accuracy the dynamic behaviour of the plant components has to be taken into account. One of the key improvements in regard of the proposed AFP-production plant is the combined use of the linear unit, the industrial robot and machine tooling. Due to a comprehensive knowledge of the structural behaviour further improvements of these single components can be derived.

Industrial robots have serial kinematics, whereby elasticity of joints is summed und results in higher inaccuracies and misalignments. In addition, higher bending and torsion is induced through the compaction force of about 2kN applied by each processing robot unit. As a result of coordinated work with several robot units in one workspace the absolute accuracy of every unit can be used.

Therefore, to realize an improved production quality DLR develops a sensor system that compensates inaccuracies. The overall sensor system is divided into three categories (cf. Figure 4).

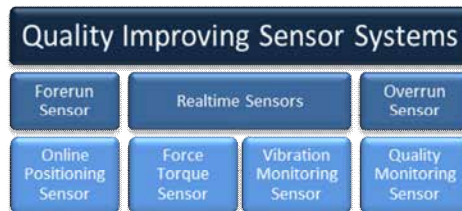


Figure 4: Quality improving sensor systems for the fibre placement process

The online positioning sensor detects in the forerun of the compaction roller the edge position of a neighbour material and is able to start a robot path correction to control material gaps and overlaps. The sensor is a laser light section sensor. Hereby, a laser light section is projected on the measurement

surface. The reflexions of the laser line are acquired by an optical sensor, mostly a CMOS sensor. By means of triangulation a topographic 3D-measurement can be realized and geometrical steps like material edges can be detected metrically. The online positioning sensor is integrated into a real-time evaluation unit which is directly embedded into the NC-control. If the position of the material edges is way beyond defined tolerances, the online positioning system realizes an online path correction of the robot unit. (Krombholz et al. 2011)(Krombholz et al. 2012)

The real-time sensor system consists of a force-torque and a vibration monitoring sensor. The layup quality of prepreg or dry fibre material is especially influenced by several process parameters. Next to the material temperature, air humidity and feedrate, the compaction force is an important factor to minimize air pores, bridging effects and increase tack characteristics between tool and first ply as well as interlaminar. A control of the compaction force and torque along the compaction area is necessary. Therefore all layup units in GroFi® have a force torque sensor next to the compaction roller that measures the values online. A realtime unit processes this values as a function of the current robot pose and communicates with the robot NC-control. The NC-control is able to initiate corrections of the compaction force by means of pressure or robot position corrections. On the one hand side this enables an online control of the compaction force and on the other hand an homogenous force distribution along the roller. Additionally, a material optimized production, e.g. of pressure-sensitive materials such as sandwich cores, is given.

As an essential criterion in engineering the dynamical behaviour of the performing structure beginning at the platform up to the last active robot axis is studied. The last active axis means the last controllable axis on which the lay-up head is mounted. As one first step to overcome vibrational issues affecting the lay-up performance a dynamic study was established in (Perner et al. 2012). The results were considered for the optimization of the coupled drive control of the linear unit. Actually, these studies has to be made during the installation phase.

Vibration can be observed during the layup using accelerometers. These sensors are available with different specifications by means of frequency range and sensitivity, for instances. Since the robot structure itself is heavy weight, the influence of the sensor's mass on the response of the structure can be neglected through signal analysis. The filter device for signal condition separates disturbances from the target acceleration. In the case that the oscillations during the layup process exceed the defined limits, a compensation movement is initialised. Unfortunately, the dynamic behaviour of the drive engines is not capable to compensate for deviations through frequencies higher than about 40Hz. Therefore, the online monitoring of vibration by likewise accelerometers forms the input signal for a compensation which is part of future investigations.

Beside of the sensor systems to increase the layup quality, e.g. by online path corrections, an online quality monitoring is necessary. Nowadays, experts control the laminate ply by ply or sequence by sequence. This results in dead times of the production facility by an average of 15min per ply in case of the fuselage production. An overall dead time for quality inspections in the production of large scale aeronautic parts is estimated to 4-6 hours. To realize a highly productive fibre placement facility the inspection time has to be minimized. As a consequence, the DLR develops an online quality monitoring system. The sensor system is mounted in the overrun of the layup head and performs the visual inspection fully automated and within the layup process. In this way the manual inspection is substituted or minimized by localising incorrect areas for a detailed manual inspection.

The quality monitoring sensor is based on a laser light section sensor with a much higher resolution optical sensor. The scan width represents the full material width of 16 x 1/4" tows. The major task of the sensor system is the detection and survey of material gaps and overlaps, misalignments and foreign bodies. To realize a real-time solution, the optical sensor uses a real-time processing unit that is directly connected with the NC-control. Based on the measurement results, corrections can be initiated within the process. Moreover, the measured edge contour can be used as the base for the forerun online positioning sensor to detect neighbour material courses.

The quality improving sensor system, based on forerun, real-time and overrun sensor systems, meets the requirements for a high precision and productive fibre placement process. The result for the industry will be the development of a layup technology with at least the same quality for a more flexible and cost efficient production of composite structures.

6 SUMMARY AND CONCLUSIONS

Within this manuscript, tasks of the DLR project GroFi® were introduced. At first, a novel robot based fibre placement facility was demonstrated that consists of up to 8 coordinated layup units. These layup units are equipped with fibre placement or tape laying heads on a rail system. In addition, a new CAD-CAM simulation was presented to schedule these units to achieve an efficient production process. Despite the usage of standard industrial robot units a sensor concept was demonstrated that increase the quality of the composite structures.

It was shown that the requirements of the actual aviation industry could be addressed successfully.

Further studies will show up new theoretical and practical knowledge of the advanced automated fibre placement process, especially in the fields of coordinated multi-head facilities and simulations but also in the interaction of different sensor systems.

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Manufacturing Paradigms

ENABLING INITIATION OF A LEAN MANAGEMENT SYSTEM IN SME'S: A CASE STUDY OF A HIGH PERFORMANCE PLASTICS MANUFACTURER

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ABSTRACT

This paper investigates the challenges in developing a Lean Management System in a typical Small to Medium Size Enterprise (SME's) in the UK. Through a series of pilot projects measured and implemented by action research this case study reflects on the changes in mind-set and behaviours that are required on the part of the researcher in order to implement a Lean Manufacturing System. The implementation and suggestions by the researcher to adopt the observational methods such as visual data management and Hoshin Kanri were part of the action research. The data gathered influenced management strategy and planning to incorporate lean practices in the organisation. The actions and results were achieved by the workforce commitment to ensure embedding and sustainability for the future. Benefits realised included a 21% increase in on time delivery performance and cross functional problem solving actions resulted in a lead time reduction of 8 to 4 weeks.

Keywords: Lean Management System, Performance Management, Hoshin Kanri

1 INTRODUCTION

The research has been carried out as part of 30 month Knowledge Transfer Partnership between the University of Hertfordshire, School of Engineering and Technology and a partner company funded by the UK government. This paper has limitations as it is based on a single case study, although the discussions and conclusion are practical and have been observed over a 9 month period. The overall KTP project plan is to develop, pilot and embed a coherent manufacturing and operational strategy based on the Lean Manufacturing, for roll-out across all divisions within the company's business units. The identified opportunities are to address out of date practices and standardise for team management. It is anticipated that the company will benefit from not only having a team work approach to getting things done but also to improve profit levels through sustainable increase in efficiencies. These actions will allow the partner company to offer higher value service offering to current and future clients. It is imperative that the best use is made of the newly improved staff skills available through changes in methodology as the first step, rather than making changes in technology that might be cost prohibitive in the current economic climate.

Aligning data collection, analysis and problem solution to business strategy through the lean lens in this SME partner company required attention to PDCA (plan-do-check-act) in the form of observation of the current state of affairs, problem solving, visual outcomes, continuous review, and top level management leadership and recognition. SME's characteristics which constrain actions and implementation rate were found to be, in this study, leadership, organisational culture, financial stability, knowledge base, participative employees and lack of a performance evaluation system as supported by (Pius et al., 2006) (Sanjay & Burcher, 2006).

Another common theme in SME's is the idea of utilising performance improvement tools at local level for short term gains without streamlining the flow of work (Yang & Su, 2007). The notion of "being lean" opposes the scattered utilisation of lean tools where there is limited internal connections

which is referred to as “doing lean” (Seth et al., 2008). Therefore, as strategic performance management becomes more important to operate globally, the issues above and team performance management will become more critical. If this organisation is to sustain its competitive advantage, Hoshin Kanri approach and the Lean Management System practices would become vital to the modernising and success of this company (Chau, 2008).

Lean thinking emphasises not only utilisation of tools and methods but the closed feedback loop system required for the sustainability of improvements. It allows a continuous assessment of internal and external customer-supplier relationships, so a poor performance in one link of the value chain is realised and resolved. This case study tries to demonstrate the importance of universal employee engagement and strategic alignment for problem solving (Karim & Arif-Uz-Zaman, 2013).

2 PROBLEM IDENTIFICATION

As part of the Knowledge Transfer Partnership project over 30 months, one of the objectives was to increase the number of customers. From a traditional point of view and market orientation school of thought, this would have meant to developing capabilities to gain competitive advantage based on price, product diversification or response time. Although strongly applicable to the company, the approach would have enabled short term growth and increased the current skill deficiencies. As a result a resource capability development under the lean manufacturing systems framework was taken to enhance internal capabilities to result in growth.

The initial analysis of the business performance demonstrated a very poor delivery performance followed by notable quality issues with no corrective actions but a fire fighting attitude prevailed. This was realised through assessment of the information flow utilising value stream mapping whereby critically, lack of internal communication in some cases led to increased lead time for a client. In order to develop an understanding of the business performance a study of the current measures was carried out. Table 1, demonstrates the result of analysis.

Table 1: Status at analysis using performance measures

Current performance measures				Initial measurement		
Metric	Available measure	Target	Method of data collection	Measured value	Unit	Value
Delivery performance	None	None	ERP	On time delivery performance	%	53%
Quality	Number of customer complaints	None	Manual complaint register	Internal reject,	%,	7%
				Customer complaints,	Qty,	16
				Re-occurrence of quality issue	Qty	8
Inventory	Stock value	Less	ERP	Inventory on sales	Ratio	2.76
Maintenance	None	None	Not available	Availability index	%	97%
Material availability	None	None	ERP	Supplier delivery performance,	%	42%
				Supplier quality performance		97%

Initially developed by The Bridgestone Tire Company in Japan, Hoshin Kanri was designed to align business goals and daily operations through eliminating waste in all business functions from customer relations and product design to supplier networks. A tailored Hoshin plan with defined impact levels was developed. The design of the Hoshin plan was refined to fill the knowledge gap. Using an interactive session, the full management team was involved in generating the strategy arms and conclusively agreeing the few vital factors of management.

This analysis allowed a development of top level policy as shown in Figure 1 with agreed metrics on a single goal of improving delivery performance. As ownership was instilled through the process of policy design, the clarity of leadership view was defined and issues with direct impact on the main goal were identified based on internal capability and relevant gaps.

Top level policy			
Entity	Plan owner	Created On	Last Revised
Business Situation: The objective is to improve our delivery performance while sustaining quality standards to enable future competitiveness within the market.			
Objective	Sub Level Function	Strategy	Performance metrics (Targets)
Establish ourselves as a company renowned for excellent delivery performance Performance Metrics (Targets) On time delivery (90%)	Sales	Reducing Enquiry response time	Semi Finished 100% < 24 hrs Finished 100% < 5days Repeat jobs 100%< 24 hrs
	Production	Reducing scrap & rework to <2%	Reject rate < 2%
	Purchasing	100% material availability	No. of jobs delayed/released due to material availability (1Q:5, 2Q:0)
	Logistics	Reduce stock levels	Inventory on sales ratio of 1:1
	Quality	Zero customer complaints	Number of customer complaints (1Q:6, 2Q:2)
	Maintenance	Availability of equipment	Number of delays due to availability (1Q:10, 2Q:4)

Figure 1: Top level policy derived from analysis

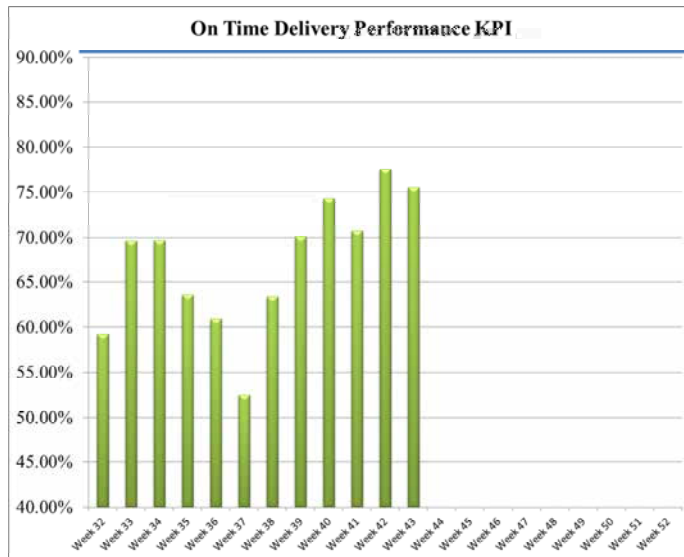


Figure 2: Policy Performance Metric Sheet

In order to maintain the cascade of responsibility each strategy owner then developed tactics to achieve the targets assigned. One of the objectives of the case study was to assess the increase in

awareness of the management team in relation to lean thinking and practicality of embedded operational strategy.

Engagement of the staff was observed resulting in an improved overall performance measure as shown in Figure 2. At time of this paper, there has been a direct feedback loop created to the board room and strategic decision making including new sales strategy, training and development requirements, capacity requirements, to an extent, are informed by this feedback of data.

To further enhance the process A3 thinking and problem solving (Shook, 2008) as the sheet in Figure 3 shows was introduced later to systematically address key issues and increase management focus on problems providing a platform for interactive problem solving in review meetings.

3 CHALLENGES

This type of research has some issues related to involvement of the researcher and the need to be mindful of the facilitation of the engagement of others in this situation as the paper on action research by (Snoeren, Niessen, & Abma, 2011) encourages the necessary engagement of the researcher. Action research is defined as follows in (Denscombe, 2007) practical, change, cyclical process and participation. These are all key characteristics of this study where the implemented actions and their influence is being measured with an expectation of delivering sustainable value and at the heart of all this there is change.

The research and the researcher in this case study faced a series of challenges including a lack of appropriate data collection systems and no cross functional problem solving. In addition, conflicts within teams hindered the process. The issue was magnified with initial avoidance of conflicts from Senior Management for progression of implementation of action items leading to visible frustration within the teams. An inherent lack of forward progress was blamed on the Senior Managers as there was a culture of making no decisions as there may be blame attached hence no decisions were made. This emphasises the need to recognise the key success factors in implementing Lean Management Systems in SME's such as leadership, matching of skills and performance evaluation systems.

4 RESULTS

This change allows the researcher to adopt the observational methods required to influence lean management thinking through visual data management and Hoshin Kanri. In addition, it implies that new methods, practices and improvements may be desired by stakeholders but the commitment of the workforce ensures sustainability for the future. Benefits realised as a result are as follows:

- 21% increase in on time delivery performance
- Significant cultural shift and an emergence of a collective management decision making system
- Development of training requirements at all levels of organisation
- Cross functional problem solving resulting in lead time reduction of 8 to 4 weeks
- Management ownership and target setting

5 CONCLUSION

For any industry, aligning business objectives within various functions of the value stream is of high importance in gaining a competitive edge. In high performance plastics manufacturing, this could be anything from the link between cost reduction policy and in process waste management, heat treatment variation and labour deficiencies or the relation of reduction in revenue generation due to response time to enquiries, quantitative and qualitative skill gap and high manufacturing lead time.

In summary, the main aspect of Hoshin Kanri, as a method for gaining competitive edge, is to focus on the very few and the cause and effect relationships underlying the effectiveness of an operational strategy. The case study found that by exposing the management team to a variety of sources of lean information and involvement in development of the operational strategy, the organisation enjoyed both financial benefits and emergence of lean thinking. The internal tacit knowledge was enhanced and knowledge transfer was embedded through involvement and engagement of employees as one and therefore "being lean".

[illegible]

Figure 3: Company Operational Excellence Report

Future research opportunity is available to assess wider issues and practicality in other SME's of implementation of methods, tools and techniques leading to a Lean Manufacturing System for an SME.

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AN INTEGRATIVE LEAN ASSESSMENT MODEL FOR DISTRIBUTION CENTRES

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ABSTRACT

It is hard to benefit fully from lean manufacturing without having an efficient distribution centre. Applying lean distribution concept helps to reduce distribution centres waste while maintains customer service level high. The purpose of this study is to develop a lean assessment model that enables distribution managers to measure and improve the leanness levels of their companies. A data driven analytical approach (i.e. factor analysis) is used to assess leanness quantitatively. A lean index score is calculated to benchmark the leanness level of four distribution companies based in Ireland and UK. Results recommend that special attention should be taken on simplifying distribution network structure, establishing long term suppliers' collaboration, managing customer demand, improving storage space utilisation, and managing distribution operations more efficiently.

Keywords Lean Distribution, Lean Assessment, Factor Analysis

1 INTRODUCTION

Over the last decade, competition between enterprises has become a matter not only of productivity but also of overall supply chain performance (Mahfouz and Arisha 2010). Distribution Centres, which are mainly concerned with storing, retrieving and connecting products through supply chain processes, play an instrumental role in leveraging supply chain performance in terms of time, quality and cost. Lean philosophy aims to achieve streamlined and waste-free operations by eliminating every negative aspects of resources consumption. Although the majority of lean publications have generally addressed production systems, lean thinking has stretched to encompass logistics and distribution activities. Lean distribution is defined as a logical extension of lean supply chain operations downstream from the manufacturing plant to create smooth product flows through the supply chain.

While many companies have applied lean concepts, more than 90% have failed to achieve measurable improvements in their system performance (Bhasin and Burcher 2006). This is largely due to the lack of lean assessment models that monitor, assess and compare leanness levels before and after applying lean practices (Soriano-Meier and Forrester 2002). Research on assessing leanness level over the last decade has focused on creating lean indices for manufacturing systems, but the problem of assessing leanness of distribution industry has not been addressed, as far as we are aware.

Hence, the paper aims to present a lean index that quantitatively evaluates the leanness performance in distribution companies. Three basic steps are followed through the paper to achieve these objectives; (1) Identify standard lean distribution performance metrics, (2) Develop an integrated lean assessment model to calculate a quantitative lean distribution index, and (3) Use the

proposed lean index to indicate the effectiveness of the proposed improvement efforts, and as a benchmark for lean performance.

2 LEAN THINKING

2.1 Lean Distribution

Supply chain management literature reflected the importance of managing distribution centres to the efficiency of production systems as well as the whole supply chain performance (Yang *et al.* 2010). Each distribution function – from order planning and processing to supplier/customer relationship management, inbound and outbound operations, and orders delivery – can benefit from the lean principles. Myerson (2012) noted that, to make distribution centres lean, distribution managers should seek perfection, high customer value, efficient warehouse management, high process quality, optimal utilisation of storage space and minimum non-value added and waste activities.

2.2 Lean Assessment Process

Few attempts were made to evaluate the lean distribution process (Wu 2002). Based on a literature review, Table 1 shows a summary of different performance metrics that are utilised to evaluate the leanness level of the distribution industry.

Table 1: Summary of lean distribution performance metrics

Authors	Lean Distribution Performance Metrics
Myerson (2012)	Driver dwell time; Labour efficiency; Space utilisation; Customer satisfaction (on-time delivery, completed orders, no-damaged parts and low prices); Warehouse productivity
Bradley (2006)	Number of damaged parts; Percentage of on-time shipments; Shipment accuracy (delays in shipments)
Jaca <i>et al.</i> (2011)	Damage parts rate; Order lead times; Worker satisfaction
Frank (2004)	Order processing times; Order lead times
Crow <i>et al.</i> (2010)	Orders delivery time; Inventory total cost

3 METHODOLOGY

3.1 Identifying Lean Distribution Metrics

Given the hypotheses proposed by Ray *et al.* (2006) – that an indicator metric could be calculated for any common set of input variables and outcomes – a quantitative leanness index (i.e. a dependent metric) can be generated from the metrics that contribute to measuring leanness performance (i.e. independent variables). This can be accomplished via an integrated lean assessment model that starts by identifying the appropriate lean metrics, then standardises and normalises them, and finally calculates the leanness index.

The Supply Chain Operations References (SCOR model) is used to identify the lean metrics of the study. SCOR has come up with different performance attributes, all of which can be linked to various lean principles (Myerson, 2012). These includes: delivery reliability, perfect order measure, responsiveness, flexibility, cost, and asset management (www.supply-chain.org). The metrics of distribution cost and asset management are not defined due to the confidentiality of the financial information in some companies. Table 2 shows a map between SCOR performance attributes, and the identified lean metrics.

Table 2: The selected lean distribution performance metrics

SCOR Performance Attributes	SCOR Attributes Description	Distribution Metric	Description
Delivery Reliability	Delivery reliability focuses on the waste in terms of shipping the correct product to the correct place at the correct time. Failure of achieving that causes in higher number of cancelled orders.	• Cancelled Orders	• The number of orders that are cancelled due to delays in shipment or delivering incorrect products.
		• On-Time Delivery Orders	• The number of orders that arrived to their final destination at the agreed time.

Order Perfection	Order perfection measure the error-free rate of the orders. Error free orders contains orders that are delivered complete with zero damage items.	• Damage-Free Orders	• The number of orders that free of damages.
		• Order Fill Rate	• The portion of total orders delivered completely, i.e., all units shipped as agreed with customers.
Responsiveness	Responsiveness measurements relate how quickly orders can be delivered to the customer	• Order Lead Time	• The average time between customers setting and receiving the orders.
Flexibility	Flexibility measures distribution agility and response time for unexpected changes..	• Orders Processing Time	• The average time of distribution inbound operations (e.g. unloading, storing, picking, packaging, loading operations).

A significant field work has been carried out to investigate the practicality of the lean distribution metrics that were addressed in the literature. A senior member and a shaper of strategies in the Irish distribution industry was interviewed to gather general information about distribution companies and the characteristics of its supply chains, as well as an overview of the industry's current awareness of lean concepts and practices. A number of interviews were then held with seven distribution industry professionals from Ireland, UK and Portugal, followed by two observational visits of distribution companies in Ireland, aiming to study the appropriateness of the selected metrics. The managers have agreed that the six metrics can be effectively used to assess the leanness performance of their companies.

3.2 Data Collection

Quantitative data sets were collected for the selected metrics from four distribution companies based in Ireland and UK. In most cases this was a straightforward process, as all required data were available from the companies' ERP systems. Further data analysis and verification were conducted on a continuous basis through meetings and phone conversations with the responsible managers. Due to the diversity of the metrics' measurement units, as shown in Table 3, data standardisation phase became a necessity in order to reduce data bias before the application of factor analysis method.

Table 3: The measurement units of the selected metrics

Variable	Cancelled orders	On-time delivery Orders	Damage free orders	Order fill rate	Order lead times	Order Processing times
Measure Unit	Quantity/Month	Quantity/Month	Quantity/Month	Percentage	Hours	Hours

3.3 Data Standardisation and Normalisation

Data standardisation is a statistical approach that resets all data to equal ranges in order to ensure data consistency and comparability. Variables standardisation involving three main steps; (1) derive a common measurement unit represents the selected variables, (2) transform all model variables to a function of the selected common variable in order to minimise potential data bias, and (3) normalise the standardised variables for comparison purposes. Labour hour (i.e. the number of man hours required to deliver an order to the end customer) was selected as the common measurement unit that were used to standardise the studied lean distribution metrics (i.e. independent variables).

After variables had been converted, they were transformed into a standard score so that data from different operational processes, with different orders of magnitude, could be normalised and thus compared on an equivalent basis (Dubes and Jain 1980). A standard score (i.e. Z score) for each variable was calculated using the formula $Z = \frac{x - \mu}{\sigma}$ where Z is the standardised independent variable, X is the original data value, μ is the sample mean and σ is the standard deviation. The normalised data sets were then processed statistically, and the outputs examined to determine the best model for the proposed leanness index.

3.4 Factor Analysis (FA)

Factor analysis (FA) is used in describing patterns of relationships between quantifiable variables that

cannot be measured directly (Pett *et al.* 2003), and is composed of a multivariate group of methods that enable various measurement dimensions in data sets (Hair *et al.* 1987). It seeks to derive interpretable common factors from extensive sets of data and then evaluate variables that cannot be measured quantitatively or collected directly from the companies involved (e.g. leanness levels, product evaluation indices, and competitive strategies) (Zhang and Ray 1995).

FA starts with deriving common factors by amalgamating the number of independent variables into a smaller number of factors, whose numbers are determined using a component matrix. The component matrix showed that a 2-factor model was used as it accounted for 73.8% of total data variance. A 3-factor model is not feasible since the third factor had a variance less than 1.

The significance of the lean distribution metrics and their correlation with the extracted factors, from the component matrix, is shown in Table 4. Determining the loading of each variable on the factors helped to identify variables' magnitude: any variable loading less than 0.4 on all factors should be eliminated (Tabachnick and Fidell 2007). Given that all variables' loaded at over 0.4 on at least one of the two selected factors, as shown in Table 4, they were retained for the next analysis step.

Table 4: Pattern and structure matrix for FA

Variables	Pattern Coefficient	
	Factor 1	Factor 2
Cancelled orders	.465	.816
On-Time delivery orders	.369	.817
Damage free orders	.924	
Orders fill rate	.755	-.409
Order lead times	.90	
Order processing times	.502	

To obtain reasonable definitions for the leanness factors, the variables were grouped according to their loadings on the factors. Factor 1 had the highest loading on 'Damage free orders', 'Order fill rate', 'Order processing time', and 'Order lead times' suggesting these variables could be grouped into a single factor labelled '*Distribution quality and flexibility*'. In the same way, the second factor, which had significant loading values with 'Cancelled orders' and 'On-time delivery orders' is more associated with '*Distribution Accuracy*'. Once the two factors were defined, the factor scores (i.e. weights) were calculated using the component score coefficient matrix (Julie 2007), Table 5.

Table 5: Factor score matrix

Component Score Coefficient Matrix		
Independent Variables	Factors	
	Distribution Quality and Flexibility	Distribution Accuracy
Cancelled orders	0.114	-0.498
On-time delivery orders	0.185	0.552
Damage free orders	0.323	-0.25
Order fill rate	0.244	-0.216
Order lead times	-0.332	-0.149
Order processing times	-0.192	0.158

The selection of a variable's factor score in Table 5 is related to its loading in Table 4 – pattern coefficient columns. The coefficients of 'Cancelled orders' and 'On-time delivery orders' are highly correlated to the second factor in Table 4, so their factor scores can be obtained from 'Distribution Accuracy' column in Table 5: the same applies for 'Damage free orders', 'Order fill rate', 'Order processing times', and 'Order lead times' which are highly correlated with the first factor in Table 4, so the factor scores in 'Distribution quality and flexibility' column at Table 5 can be used. Table 6 illustrates the final factor scores of the six leanness variables.

Table 6: Factor scores for the studied variables

Variables	Factor Scores
Cancelled orders	-0.498
On-time delivery orders	0.552
Damage free orders	0.323
Order fill rate	0.244

Order lead times	-0.332
Order processing times	-0.192

To assess companies' leanness levels and prioritise the proposed efforts to improve their performance, an individual lean index for each variable is calculated by multiplying variable's score by its factor score, and the overall leanness index by summing the variables' lean indices as illustrated in Equation 1.

$$\begin{aligned} \text{Lean Index} = & -0.498 * \text{Cancelled orders} \\ & + 0.552 * \text{On-time delivery orders} \\ & + 0.323 * \text{Damage free orders} \\ & + 0.244 * \text{Order fill rate} \\ & - 0.332 * \text{Order lead times} \\ & - 0.192 * \text{Order processing times} \end{aligned} \quad (1)$$

Since the interpretation of the variables' factor scores is 'the higher the score, the more impact the variable has on the company's leanness', increasing the number of on-time delivery orders, damage free orders and orders fill rate contribute significantly to increasing leanness score, and larger number of cancelled orders and longer order processing and lead times will detract from its leanness value.

4 FINDINGS AND ANALYSIS

The developed leanness index is used as a scale for the leanness performance of the four studied distribution companies. The results showed that company D is the leanest, with an overall Lean Index score (LI) of 1.03; the next leanness is company B (Lean Index score 0.47), followed by companies A (LI -0.07), and C (LI -0.48). Analysing such leanness scores is important, especially in terms of identifying the challenges that these companies face and the impact of their characteristics on their leanness performance.

4.1 Analysis of Companies' Leanness Scores

Company D: Several factors contributed to the high leanness score of the company - including the robust long term relationships it has with its customers, the efficiency of its ordering process and the standardisation of its warehouse operations. These factors resulted in significant improvements in the values of 'On-time delivery orders', 'Damage-free orders' and 'Cancelled orders' metrics. Despite that, the company still has room to improve, as the complex structure of its distribution network and being far-distance of its suppliers cause long 'Orders lead time'.

Company B: The firm sets up standard agreements with its suppliers, resulting in faster 'Order processing time' and more accurate supplier delivery process which increase the 'Orders fill rate'. SKU's are usually stored in random locations in the warehouse, causing longer storing and picking times, which in turn increase the 'Order lead time'. Operational times and costs, and the numbers of damage free items, can be significantly improved if class-based storage practices are applied and warehouse floor is more logically organised. Although the company has its own fleet for deliveries, optimal vehicle routing plans are needed in order to improve the 'On-time delivery' and 'Cancelled orders' metrics.

Company A: The Company scored short 'Order processing times' and 'Order lead times' due to the efficient management of customer demand, the error-free transaction of information (via its advanced ERP system), and the close locations of its suppliers. Being a part of a wider network of depots for a big brand name in the tire industry, its supplies can be controlled by strict central logistics policies which sometimes conflict with customer requirements. The restrictions imposed by manufacturing or economic constraints on supplying specific items to the depot cause frequent stock-outs, significantly increasing the numbers of 'Cancelled orders' and lowering the 'On-time delivery orders' and 'Orders fill rate' scores. To mitigate the negative influences of these challenges, the company is advised to create new collaborations and partnerships with alternative sources (e.g. suppliers or bigger distribution centres) and efficiently manage its inventory levels.

Company C: Looking at the company's conditions gives a better understanding of its lean metrics scores. SKUs are usually replenished after long price negotiations with suppliers, making for longer 'Order processing time'. The company expects its 'Order processing time' will be greatly reduced

when a standard agreement with suppliers is created. Another problem is that the warehouse floor is disorganised, with items usually stored in random locations, resulting in inefficient picking operations and in turn longer ‘Order lead times’ and higher ‘Numbers of damaged parts’. Its suppliers are far away, and the structure of its distribution network is complex, both contributing to increased ‘Orders lead time’ and lower ‘On-time delivery orders’ scores.

5 CONCLUSION

Lean in manufacturing has reached its maturity phase however in distribution centres it is still in the introduction phase. Finding ways to successfully implement and assess leanness in distribution centres are urged by operations and supply chain managers. The calculated leanness levels of the studied companies have indicated that the better and more efficient the management of customer demand, error-free information transaction, long term collaboration with suppliers, and organised storage space the more the positive impacts are on orders perfection, delivery reliability, responsiveness and flexibility. There are a good potential to extend this research work to include more distribution companies within supply chain networks. The number of companies that contributed to this study is considered a limitation. Increasing sample size and include more companies in the benchmark exercise will add value to the verification of the index and the recommendations for improvement.

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IMPLEMENTATION OF A LEAN SIX SIGMA APPROACH IN THE MANUFACTURING SECTOR: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Lean Six Sigma is a continuous improvement methodology that aims to reduce production costs, improve organisational capability, and maximise the value for shareholders. This paper aims to explore the most common themes within LSS in the manufacturing sector, and to identify any gaps in those themes which may be preventing users from getting the most benefit from their LSS strategy. This paper also identifies the gaps in current literature and develops a research agenda for future research into Lean Six Sigma themes. The following research is based on a Systematic Literature Review of 33 papers which were published on LSS in the top journals in the field and other specialist journals, from 2000 to 2012. There are important themes cited in this paper which are; Critical Success Factors, benefits, motivation factors, limitations and impeding factors. However, there are many gaps and limitations that need to be covered in future research.

Keywords: Lean Six Sigma, Manufacturing, Systematic Review

1 INTRODUCTION

Today, Lean and Six Sigma are the most popular business strategies for enabling continuous improvement (CI) in the manufacturing, service and public sectors, and CI is the main goal for any organisation wishing to achieve quality and operational excellence and to enhance performance (Thomas et al. 2009). The integration of the two approaches improves efficiency and accuracy and helps to achieve CI faster than the implementation of each approach in isolation (Salah et al. 2010).

This interest in LSS has led to many attempts to come up with a comprehensive approach to achieve CI. There are noticeable limitations in the fields of research into areas of LSS (Kucner 2009; Chakravorty and Shah 2012; Laureani and Antony 2012; Kumar et al. 2006), but the benefits of applying Lean and Six Sigma in parallel are noted in many case study papers in both the manufacturing and service sectors (Akbulut-Bailey et al. 2012 and Hardeman and Goethals 2011). It is also significant that the number of available papers on LSS, though still small in comparison to other CI tools, is showing exponential growth since the first papers were published in 2003.

1.1 Lean Six Sigma

Lean Six Sigma is not new, it is a combination of Lean Management and Six Sigma methodologies which were first integrated in 1986 in the US-based George group. The term 'Lean Six Sigma' did not appear in literature until 2000 (Timans et al. 2012), and LSS teaching was not established until 2003 (Kubiak 2011). Since that time, there has been a noticeable increase in LSS popularity and deployment in the industrial world; especially in large western organisations such as Motorola, Honeywell and General Electric (Timans et al. 2012; Laureani and Antony 2012) and in some small and medium size manufacturing enterprise (SMEs) (Kumar et al. 2006).

LSS is "a methodology that focuses on the elimination of waste and variation, following the DMAIC structure, to achieve customer satisfaction with regards to quality, delivery and cost. It

focuses on improving process, satisfying customers and achieving better financial results for the business” (Salah et al. 2010). Organisations give many reasons for implementing LSS; to improve business performance and operational efficiency for example, especially given the growth of global markets, to improve product quality, reduce production costs and so improve customer satisfaction (Antony 2008; Snee 2010; Laureani and Antony 2012; Jayaraman et al. 2012).

The history of LSS and notable success stories of LSS implementation in the industrial world can be seen in many academic papers by authors such as Chakravorty and Shah (2012) and Thomas et al. (2009). On the other hand, not all organisations can gain real benefits from LSS implementation; a poor attempt at LSS implementation can actually render it ineffective (Jayaraman et al. 2012).

2 METHODOLOGY

This paper explores the most important Lean Six Sigma themes that have been published in academic journals, by systematically reviewing the literature. According to Okoli & Schabram (2010), a Systematic literature review is “a systematic, explicit, comprehensive and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners”. Tranfield et al. (2003) has stated that systematic review has become a ‘fundamental scientific activity’.

To date, only two systematic reviews have been published in LSS, which were carried out by Glasgow et al. (2010) in healthcare, and a general review by Zhang et al. (2012). Authors have argued that there is a clear need for more systematic reviews to be done in the field of Lean Six Sigma, to bridge the gap in previous literature.

This paper is, therefore, going to systematically review all the papers that were published in top journals and specialist journals in Lean, Six Sigma and LSS from 2000 to 2012. It will explore the most common themes that have been published in the field of LSS, and explore the gaps in each theme, in the manufacturing industry. Top journals are determined by using the journal ranking lists in the International Guide to Academic Journal Quality (ABS 2011) and Harzing (2012).

The process and the phases of this approach were adapted from several academic sources, such as Okoli and Schabram (2010) and Tranfield et al. (2003) as shown in figure 1.

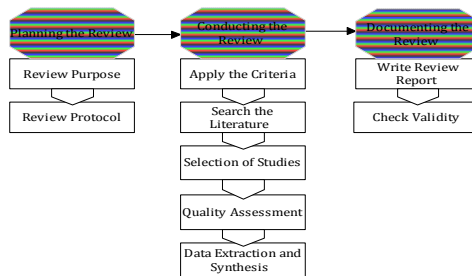


Figure 1: Research phases and process (Okoli and Schabram 2010 and Tranfield et al. 2003)

2.1 Material and outcomes

The ‘journal’ search for research literature was done through 20 top academic journals and 7 specialist journals in the field of Six Sigma, Lean and LSS, published in seven well known databases such as Emerald, American Society for Quality (ASQ), Elsevier and so on. Search strings were used as follows: [(lean) or (six sigma) or (lean six sigma) or (continuous improvement) or (Toyota production system) or (process management) or (lean management) or (lean thinking) or (lean manufacturing) not service] or [(lean and six sigma) or (lean sigma) and (manufacturing) and (case study)]. Meanwhile, the literature search was limited to the English language only. This search of journals and databases illustrated that there were no research articles related to Lean Six Sigma to be found before 2003. The search results were sorted into Critical Success Factors, benefits, motivation factors, limitations, impeding factors and future research. The data collected for analysis and the key findings of this paper have been presented in graphical form to make them easier to understand.

During this Systematic Literature Review, 33 papers containing 21 case studies published in the manufacturing sector in various countries (US, UK, India, Netherlands, China and New Zealand) were examined. This paper aims to explore the Lean Six Sigma themes deemed of most benefit to the manufacturing sector, and also to highlight any gaps and give recommendations for future research.

3 RESULTS AND DISCUSSION

3.1 Critical Success Factors for LSS Implementation

CSFs - “those factors that are critical to the success of any organisation, in the sense that if the objectives associated with the factors are not achieved, the organisation will fail” (Timans et al. 2012; Laureani and Antony 2012): organisations can ensure success if they direct their effort and focus onto the critical success factors. Figure 2 presents over 20 different critical success factors that appeared in the 21 case studies. Training and education was the most frequently cited factor, followed by communication and top management commitment and involvement. Other factors such as organisational culture and project selection & prioritisation appeared to be less important. However, CSFs varied from study to study and from company to company as well as between countries. CSFs cited as important in some studies were found to be less important in others; for example, studies in the Malaysian electronic manufacturing service (EMS) industry and the Netherlands SMEs manufacturing found that project selection and prioritisation was insignificant (Jayaraman et al. 2012), on the other hand, this factor was cited as one of the most important by other sources such as Snee (2010). Unique CSFs also emerged, such as; the development of project leader’s soft skills, the need to give LSS implementation the time it needs, encourage LSS thinking in employees’ daily activities and results sustainability. These variations in CSFs could be as a result of different cultures in different countries, but this gap needs to be bridged by future research.

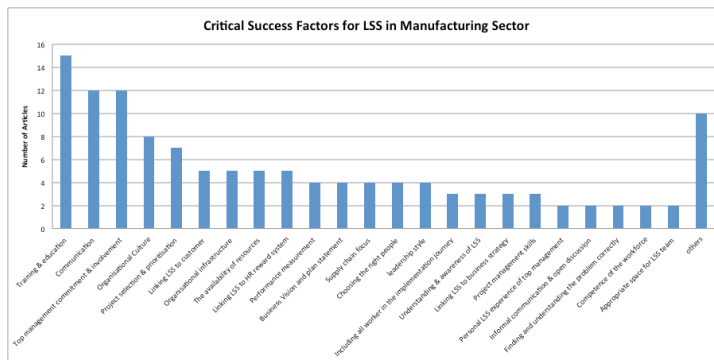


Figure 2: Critical Success Factors for LSS in the Manufacturing Sector

3.2 Benefits of successful LSS implementation

More than 50 benefits were identified in the 21 case studies, and these are presented in figure 3. The most frequently stated benefits were; increased profits and financial savings (up to \$3bn in some cases) (Corbett 2011), increased customer satisfaction (in around 50% of the reviewed papers), reduced costs and significantly reduced cycle time. Kucner (2009) states that in Navy commissioned nuclear aircraft carriers in the US, lead time was reduced from 180 days to 40 days. A number of cases cited a reduction in inventory & in-process waste as well as a reduction in the percentage of production defects. Moreover, three companies achieved Six Sigma levels due to the successful implementation of LSS in their organisations. Six companies experienced reduction in machine downtime and machine setup time. Other benefits such as; identifying different types of waste, development in employee morale towards creative thinking and reduction in workplace accidents as a result of housekeeping procedures also appeared in a number of cases. The authors observed a rich seam of publications stating LSS benefits in the manufacturing sector, but no studies were found

reporting a failure of LSS implementation. There may be many reasons for this; businesses are presumably not keen to spend time and effort preparing studies for publication that only demonstrate failure, or it may be bias in selection of articles for publication by the various journals who only want to report successes. The fact remains that this is a significant omission; publication of detailed analysis of failed implementations or projects would be of great benefit to those businesses contemplating LSS implementation in the future.

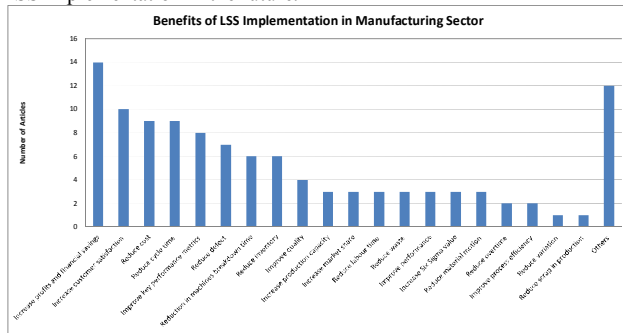


Figure 3: Benefits of LSS Implementation in Manufacturing Sector

3.3 Motivation factors for LSS implementation

17 different factors that motivate manufacturing companies to implement LSS are shown in figure 4. The top 3 are; to improve product quality & manufacturing operations; to increase customer satisfaction, attraction & loyalty & to change the competitive position in the market or to stay in competition in the international market. 6 companies were also motivated to implement LSS to reduce cost by different methods such as; reduce production cost or reduce defects in production. A number of factors have appeared in only one study, for example Chakravorty and Shah (2012) stated that implementation of LSS could improve employee morale. This view is supported by a single case study done by Vinodh et al. (2012) in Rotary Switches Manufacturing in India. This factor needs to be supported by more research to explore the relation between LSS implementation and the human side.

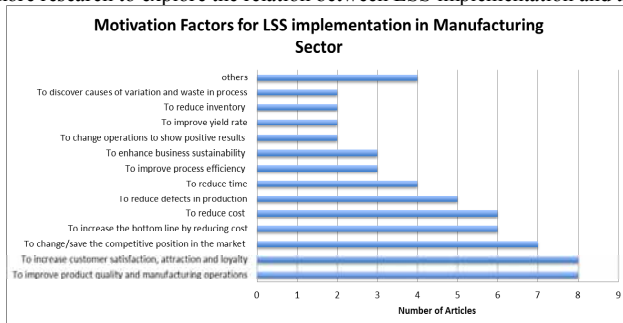


Figure 4: Motivation Factors for LSS implementation in the Manufacturing Sector

3.4 Limitations of LSS

8 fundamental limitations in LSS implementation are shown in figure 5, and these are a rich area for future research. Absence of clear guides for LSS implementation, especially in the early stages came first; practitioners need a clear guide to which strategy should come first; Lean, Six Sigma or LSS (Snee 2010; Kumar et al. 2006), and which tools should be used, when and how (lack of understanding of usage of LSS tools & techniques came third). Lack of LSS curricula was also cited by many researchers; all argue that strong LSS curricula are needed in order to leverage learning in

organisations (Salah et al. 2010). Hence, developing curricula for LSS has emerged in this paper as an area for future research.

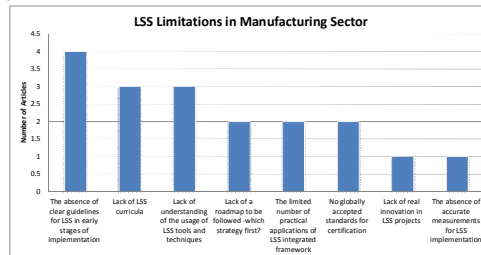


Figure 5: Limitations of LSS in the Manufacturing Sector

3.5 Impeding factors for LSS implementation

The implementation of any LSS programme needs to overcome impediments, and figure 6 demonstrates the 7 major impediments found in this study. The most significant included lack of awareness about LSS benefits in business (Snee 2010), unmanaged expectations and lack of availability of resources (Timans et al. 2012). Given the large amounts of information available about successes from LSS implementation, it is clear that it is a lack of visibility of results rather than lack of tangible results that is at issue here. Other factors included lack of training and coaching, employee reaction towards a new business strategy and convincing the top management about the benefits of LSS in business (Vinodh et al. 2012; Kumar et al. 2006). This last is due to a belief by top managers that investment in quality improvement programmes is no more than wasting money and increasing production cost (Kumar et al. 2006).

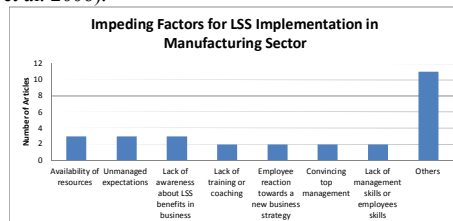


Figure 6: Impeding factors for LSS implementation in the manufacturing sector

3.6 Future research into LSS

The review of the 33 available papers has identified many weaknesses in previous research into LSS, and further work is clearly needed to bridge the gaps in available literature. There are many and varied accounts of successes and benefits accrued by the manufacturing sector, but not one publication reported failure of implementation of LSS in the same sector. It can be argued that publishing failure stories can definitely guide future research effort in the field.

Further investigation and work is needed in areas such as; problem identification; accurate and rigorous measurement systems to both establish a baseline and measure improvements; establishing clear guides to implementation for both managers and practitioners covering which strategy to adopt, and which tools to use, when and how, plus the role and skills of the LSS facilitator, including choosing an appropriate facilitator from inside or outside the organisation (Antony 2008; Kumar et al. 2006; Chakravorty and Shah 2012).

Research is also needed into areas such as the relation between LSS implementation and the human factor, formal training and certification systems and standards for MBBs, BBs and other practitioners, and finally the sustainability of LSS and proof that the integration of Lean and Six Sigma into one strategy really does help businesses to achieve world class results.

4 CONCLUSION

Levels of LSS deployment are increasing, especially in large organisations in the US, UK and the Netherlands, and in some SMEs in developing countries such as India; the number of available LSS publications is increasing accordingly. The application of LSS methodology in 21 case studies in the manufacturing sector has demonstrated the significant benefits that can be gained, and around 30 CSFs are cited in this paper, along with motivation factors. Equally importantly, the limitation and impeding factors which need to be overcome are also stated. There are many gaps in the available literature that need to be covered in future research, and although a great deal of work has been undertaken on individual Lean and Six Sigma themes, in the past there has been little written on Lean Six Sigma as a coherent strategy for business improvement, and this is one of the more immediate gaps that needs to be bridged.

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AUTOMATION FROM LEAN PERSPECTIVE-POTENTIALS AND CHALLENGES

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ABSTRACT

The competitive climate of production and high labour cost, motivate western companies to use technologies like automation as a mean to increase manufacturing competitiveness. On the other hand companies are aware about cost reductive policies like lean production which has shown noticeable achievement, consequently some manufacturers tend to follow such system. In this situation, in order to have lean enterprise, it is vital to find a clear picture of challenges and potentials of implementing automation within a lean environment. So, finding the right level and type of automation becomes vital for companies, and achieving this is not possible without a lean development of automation. The paper presents an overview of automation development from a lean perspective. The focus is on manufacturing and a case study in the automotive industry is presented. Challenges and potentials of automation are pinpointed and some suggestions regarding automation development is given.

Keywords: Lean automation, automation development, competitive manufacturing

1 INTRODUCTION

A competitive market has forced many companies towards cost saving policies such as lean manufacturing, which is a common strategy within industry initiated by Toyota. Lean manufacturing, also called Toyota Production System (TPS), is customer oriented and emphasizes on process simplicity, less human effort, less scrap, less work in process and inventory, smaller manufacturing space, lower investment in tools etc. (Womack et al., 1990). Researches show that companies which have adopted lean manufacturing often reach competitive advantages compared to competitors (Jackson et al., 2011).

Western companies are struggling to maintain their market share in competition with countries like China and India. Challenges like resource expense, high labour cost and environmental issues intensify this pressure. Among what mentioned, labor cost is an element which is more challenging for manufacturers. A study shows 33% of SMEs see human cost as an important issue and 57% mentioned that the problem with labour cost has increased in recent years (Granlund et al, 2011). In such situation, companies need to find a way to be more efficient and reduce production cost. One way in order to manage this situation is to invest in automation (Chen, I.J. and M.H. Small, 1996).

Western companies often use technology like automation as a mean to increase manufacturing competitiveness (Jackson et al., 2011). Automation is mainly divided into two categories; mechanisation and computerisation. Mechanisation mainly relates to the physical flow of goods, and computerisation refers to the flow of information (Granlund, 2012). Based on manufacturer's opinion, expressed by Frohm (2008), automation has the following main benefits: improving working environment, possibilities for increased volume capacity, better product disturbance handling, producing with a minimum of employees, improvement of productivity, cost cuts, and improved quality.

Still, automation brings some challenges in lean environments (Frohm, 2008). Reasons for this are visualization difficulties, time consuming robot planning, complexity of maintenance and complex human machine interface (HMI) (Granlund, 2012; Frohm, 2008).

In this situation, in order to have lean enterprise, it is vital to find clear picture of challenges and potentials of implementing automation within lean environment. So, finding right level and type of automation become vital for companies and achieving this is not possible unless through lean development of automation projects. The paper presents an overview of automation development from a lean perspective.

The following research questions have been addressed:

- What are the challenges of automation development in lean organisation?
- How the automation can be developed within companies to maintain lean production?

2 METHODOLOGY

To find answer of research questions, a structured literature review is performed to figure out what potentials and challenges exist in implementation of automation in lean environment. Automation for manufacturing organisations is studied by investigating literature and a case study in the automotive industry has been conducted. The case company is located in Sweden and is active in automotive industry. The company has more than 100 robots, AGV's and other types of automation solutions. Data collection methods consist of open qualitative interview, observation and document reviewing. General information regarding production system and automation has gained and two areas are specified to have more detail practical picture. During the research, case company was in process of developing two new automated facilities within production and assembly. The challenges and potentials which have come to the system due to automation development highlighted through interview with production engineers and also board managers. It has tried to see how the case company approaches toward automation development and how it could deal with development problems. In order to analyze current automation situation, direct observation, interviews with two project managers, three project engineers and two board members have done. Also reviewing the project documents have conducted. The study of automation development process has handled to present some suggestions regarding automation development considering lean principals.

3 AUTOMATION FROM LEAN PERSPECTIVE

Historically, automation has been used in early 1960's with ergonomics reasons. Working in difficult situation and lifting heavy parts are two examples of this. Afterward, industries see automation as a mean to improve quality, performance and efficiency. Automation is often regarded as the main solution to improve efficiency in manufacturing (Winroth et al., 2006). Consequently it became a key technology in manufacturing industries. According to Granlund (2012) adopted from Groover (2008), automation benefits can be presented as follow: labour productivity, reduce labour cost, mitigate the effects of labour shortages, reduce or eliminate routine manual and clerical tasks, improve worker safety, improve product quality, reduce lead time, accomplish processes that cannot be done manually and avoid the high cost of not automating.

Despite what has been mentioned before, some companies that are interested to follow lean manufacturing believe that more automation brings more complexity and even has contradict with lean principals. Some companies and specially SMED's have lack of confident to deal with automation problems and automation facilities. As a result, they are highly dependent on their automation suppliers and integrators. They also see automation with high initial cot, difficult to maintain and also with complicated interface (Granlund et al., 2011). Based on previous studies (Delkhosh, 2012; Hedelined and Jackson, 2011; Orr 1997; Haris and Haris, 2008) some automation challenges that may come to lean environment are listed as follow: high investment cost, product and process adaption and customization for the automatic manufacturing, robot programming modification for new product, human-Cell interface , human-Machine Interfaces, installation complexity, training of operators and personnel, quality issue and the ability to detect defectected products, maintenance, space occupation, visualisation, competence issue and supply issue. Some of these elements can be rephrased as complexity. For instance, problems regarding Human interface with cell and robots, maintenance, visualisation etc. A survey handled by Hedelind and Jackson (2011) reveals that operators often mention that they do not really perceive what is happening inside a

robotized cell but they see it like a “black-box”. As a suggestion to deal with complexity in production, Hedelined and Jackson (2011) have suggested three strategies:

- The development and implementation of maintenance strategies. Total productive maintenance (TPM) has been identified as a means for improving maintenance performance
- Standardize the solutions in each plant. This leads to fewer spare parts. It also reduces the need for a wide variety of special training and expertise in different technical solutions. When companies build their own automation solutions, this can easily be maintained by the production engineers themselves
- Reduce the perceived complexity of system for operators. For example, develop a user interface with the ability to sort and show the information that is really needed to handle the operation. This system collects information from other parts of system and displays them in coherent way.

On the other hand as Sambasivarao and Deshmukh (1995) discussed, before investment in automation, companies must review their strengths and weakness and develop a strategy for effective implementation. Under such circumstances it is vital to find right level and type of automation that can serve lean requirements. As Haris and Haris (2008,p1) mentioned “it is not a question that lean is manual or not- effective lean production systems use both manual and automated process-the task is to determine appropriate type of automation.” But finding the right level and type of automation is not possible unless by defining clear automation strategy (Granlund, 2012). Researches show, most of automation development projects follow ad hoc strategy and are dependent on project situation. Additionally, it is surprising that many companies still are not aware about the effects of automation strategy on their overall business trend (Granlund and Friedler, 2012). Skinner (1969) defines strategy as a set of plans and policies by which a company aims to gain advantages over its competitors and points out the importance of having a strategy and to make active choices in approach. Some researchers have published some methods to define automation strategy. For instance, Lindstrom and Winroth (2010), Safsten et al. (2007) and typical warehouse automation project steps by Baker and Halim (2007). Also Granlund and Friedler (2012) have proposed a model regarding automation development, represented in figure 2.

4 CASE STUDY RESULT

The case company develops all projects based on seven steps guideline which automation projects follow same procedure. These steps are represented as below:

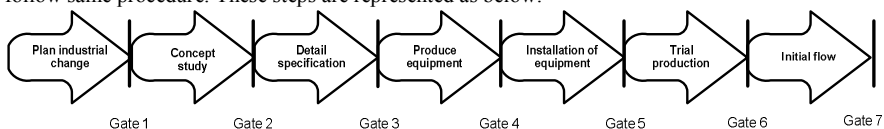


Figure 1: Project development process in case company

As it can be seen in figure 1 the project team should deliver specific tasks at the end of each phase to be able to pass the gate and enter to next step. Project development guideline starts with plan industrial change with the aim of determining policies and it continues to last step with the aim of controlling the initial flow and find the breakdowns. Each phase includes: main objective of the phase, deliverables, way of working, decisions requirements and tools and templates might be needed in time of completing the phase. This process has started to be implemented since 2010 and the two project managers that have interviewed mentioned that despite positive effect of such steps, still there are some problems with the clarification and deliverables. In some cases deliverables are not so clear to understand and project leaders do not know what exactly they should deliver to be able to pass the gates.

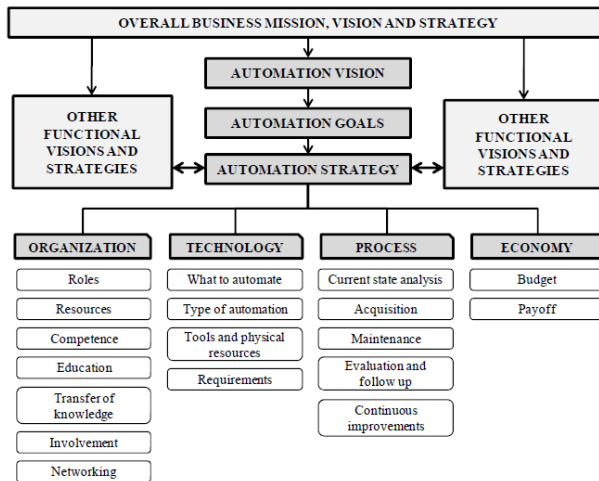


Figure 2: Automation strategy model (Source: Granlund and Friedler, 2012, p6)

Regarding automation projects, the case company follows the same process but the last four phases are handling by the supplier(s) and case company only control the process. As a result, the company asks different suppliers to present their proposals with attention to detail of specification which prepared by the company and the best proposal will be accepted considering different criteria such as cost, availability, reliability and attention to waste reduction etc. Considering the development process table1 presents automation problems which challenges the lean principals. Additionally it has found that there is a problem with automation interfaces variations. Each supplier might use his own HMI and this cause some problem with operator training and also bring some complexities to the system regarding integrating.

Table 1: Automation challenges

Automation integrating issue	Integrating different types of automation suppliers with different programming approach is a challenge for case company.
High initial cost	Robot purchasing is costly and in addition to robots it makes marginal cost like programming modification, maintenance etc.
Quality issue	Robots are not able to detect defected parts and scraps.
Visualisation	Operators and observers do not have clear picture that what is going on inside robots.
Maintenance	High mean time to repair (MTTR) is a result of complex maintenance of robots and their tools. Finding suitable spare parts, contact supplier etc.
Supplier-customer relationship	Supplier is not aware about his customer needs. Mostly suppliers due to vast range of their customers are not familiar with their customers' production strategy and situation.
Dependency on third party	Maintaining automated facilities, robot program modification and integrating the facilities are some examples of dependency to third party due to lack of competence for the company.
Training	Training the operators and involved people in automated area takes longer time and needs more complicated training.

Also programming of robot cells is a problem that the case company is dealing with. For instance, it is so common to have a problem with robot visualisation system and this needs supplier(s) to modify the programming and in some cases even the vision system needs to be replaced with new system. Further

to this, it has found that in automated cells, operators do not tend to find the cause of stops and prefer to restart the cell as a solution. Regarding this, in time of break downs, if the operator cannot solve the problem, will ask the maintenance team for help and sometimes operator cannot detect the right cause of the problem and maintenance team need to spend extra time and effort to find the cause. On the other hand, automation level is an issue that varies from one project to the other one and almost there is no determined method to define automation level in case company. This depends on project team decision and their experience and also supplier(s) suggestions. Also, automation type is highly depends on supplier(s) and there are some examples of simple solutions offered by integrators which these solutions could be existed in whole factory but due to suppliers variations, the offered solutions are different. Investigating the layout of one automated cell shows current situation is not optimized and even robot movement analysis reveals that there are some non-value added movements in the robots.

On the other side of extreme, automation potentials from interviewee's point of view are presented in table 2.

Table 2: Automation potentials

Reducing production and human resource cost	Robots can continue working nonstop. Concerning high human cost in Sweden and working rules which let all operators to have 5 weeks holiday during a year, automation is cost reductive.
Ergonomics	Weight and size of many products, need lifting help tools. In such situation robots can handle the handling process much easier than operators with less ergonomic risk.
Availability	Comparing to human source, robots do not need vacation, rest or changing shifts. As managers express, almost all robots have the availability more than 90%.
Production capacity improvement	As mentioned earlier, the high availability rate of robots will end to production capacity improvement.

5 ANALYSIS AND SUGGESTIONS

The research result shows that it is vital to see automation through holistic view. Based on the empirical findings, the case company has lack of long term and holistic view toward automation. There is no published strategy toward automation and project managers -despite the existing of project development guideline- follow ad hoc strategy regarding automation. As a result of this situation, the case company has not enough automation competence and is highly depends on the suppliers and system integrators. For instance, cell interfaces are different and are designed based on supplier's opinion and also automation solutions do not guaranty to follow lean principals and avoid losses. According to paper aim, some suggestions regarding problems and challenges found in the case company has given as follow: As mentioned in literature review, the case company should have clear automation strategy driven from overall business vision. In this respect, it is vital to pinpoint strengths and weaknesses regarding automation competence. The observations in the case study confirm that there is a need to increase the automation competence especially in robotic as well as designing simple automation solution. This can be represented as in-house development of solutions which would help the case company to decrease the level of dependency to suppliers and system integrators and also decrease the initial costs of developing automation projects. In-house development and increasing competence level would be helpful to deal with maintenance issue. Complicated automation facilities need more complicated and expensive expertise to maintain the system (Hedelind and Jackson, 2011). In order to overcome the challenge of supply, it is recommended to define clear scope of supply and also reduce the number of suppliers and integrators. Training issue needs knowledge sharing around organisation. In the case company, sometimes it is difficult to find the data regarding automation history, robots and so on. In order to understanding the historical data it is necessary to meet the project manager and ask for declaration. Cooperation with different system integrators and suppliers cause problem in HMI's. It is suggested to publish internal standard regarding HMI design and ask suppliers to follow the internal standard. This will also help to

have easier training and reduce the complexity. Regarding quality issue, increasing the level of human touch in automated cells can be helpful.

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AN EMPIRICAL ANALYSIS OF LEAN SIX SIGMA IMPLEMENTATION IN SMES – A MIGRATORY PERSPECTIVE

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ABSTRACT

The purpose of this paper is to investigate the migratory nature of Lean Six Sigma (LSS) implementation in manufacturing based SMEs in the UK. The companies were surveyed at two points over a five year period. These periods were before and after the 2008 recession point and were identified in order to assess the level of LSS implementation as a result of the tougher economic climate that has prevailed in the manufacturing industry since 2008. Analysis is carried out on a sample of 96 manufacturing SMEs from a range of manufacturing sectors in the UK. Data was gathered from company CEOs via a triangulated method of questionnaire, direct observation and interviews. The findings show the dynamic nature of LSS implementation in SMEs. Further work will be required to extend the LSS categorisation system to provide a wider category set that further defines the dynamical nature of LSS implementation.

Keywords: Lean Six Sigma, Strategy Migration, Paradigm Adoption.

1 INTRODUCTION

Lean and agility are widely considered as Business Process Improvement (BPI) strategies that have facilitated high levels of sustainable growth in many manufacturing industries throughout the world (Hines & Rich, 1997). Over the years many academics and practitioners have attempted to integrate the two approaches through proposing the concept of 'Leagility' (Childerhouse & Towill, 2000) and later, 'Agilean' (Cox et al, 2007) since it was hoped and proven in some cases that an integrated system of creating a Lean yet highly responsive manufacturing system was beneficial to a range of companies dealing with the increased threat of globalization and low labour cost competition. Over the past ten years or so Six Sigma has been hailed as a key business improvement approach that is capable of achieving significant improvements in business process performance. Companies such as Motorola and GE have based their business process strategy around the Six Sigma concept.

As companies have continued to seek ways of delivering greater business performance at lower cost, the concept known as Lean Six Sigma has come to the forefront. Early developers of the Lean Six Sigma approach (George, 2002) seemed to concentrate on a simple connection between Lean and Six Sigma proposing that the business should be "Leaned up" first and then Six Sigma could then be introduced as a mechanism to reduce variation in a process and thus improve quality. Others proposed that the 'Lean' part of Lean Six Sigma could be brought in at the Improve stage of the Six Sigma DMAIC process thus effectively demoting Lean to a secondary process (Breyfogle, 1999). Later development of Six Sigma showed its application as an effective general business process improvement strategy (Amheiter & Maleveff, 2005). However, Six Sigma and Lean Six Sigma and its associated DMAIC cycle can be seen as a simple yet powerful five stage methodology however, it can be argued that it has limited strategic capability in its current form (Thomas et al, 2009). Above all, manufacturing SMEs need to be cognisant of the need to implement a coherent BPI strategy to run alongside its production management and technology strategies in order that the company becomes

sustainable and fit for purpose (Pham et al, 2009) . As competition from low labour cost economies increases, manufacturing companies (especially SMEs) continue to move towards the implementation and effective operation of Lean Six Sigma to remain competitive by offering higher levels of product customisation and technical services while maintaining Quality Cost and Delivery (QCD) performance in the global manufacturing market.

1.1 WHY SMES

At a base level, the requirement to develop a robust BPI programme in order to improve productivity, quality, range of products and other performance measures is now paramount (Zhang et al 2004). Despite the clear evidence for a need to develop and implement BPI approaches into SMEs to ensure survival and sustainable growth, many companies are reluctant to move towards the application of LSS (and other methodologies) since they feel that major investment is required and the full benefits of applying LSS in to companies is only really felt by larger companies. Also, SMEs in many instances believe that the benefits that LSS implementation brings to the average SME are not fully appreciated by companies (Kumar and Antony, 2008). This, along with the fact that SMEs perceive that they do not have the statistical infrastructure to support LSS severely limits their success in various BPI initiatives (Thomas et al, 2009).

Therefore, with some development already undertaken in delivering effective Six Sigma solutions in to SMEs, this paper attempts to identify the migratory characteristics observed in relation to the implementation of LSS into the business processes of manufacturing based SMEs in the UK. This paper attempts to answer the following questions:

1. Are we able to identify whether the rate of LSS implementation in manufacturing SMEs has grown between the two survey periods and hence establish whether the recession has influenced companies to employ LSS in an attempt to reduce waste and increase operational performance?
2. Are we able to identify whether SMEs have continued to increase the use of LSS in their respective companies and have migrated towards becoming expert in development and application of LSS?

In order to answer these questions, a two stage survey was developed. The initial survey was undertaken between 2006 and 2008. However, soon after survey closure in 2008, the UK went in to recession. The authors then identified an opportunity to revisit the companies surveyed on the initial investigation in order to investigate how company attitudes towards the implementation of LSS had changed and whether the companies had increased the level of LSS implementation as a result of the recession. Therefore, a second survey was undertaken between 2009 and 2011 and measured the rate at which the same SMEs had adopted Lean Six Sigma (LSS) during the period between the surveys.

2 THE SURVEY – ITS DESIGN AND IMPLEMENTATION

An initial large scale survey into identifying the attitudes and capabilities of SMEs towards LSS implementation was initiated in 2006. From an initial survey sample of 150 companies, 96 manufacturing SMEs agreed to take part in the survey work. These were subsequently visited and assessed over a two-year period. A team made up of manufacturing researchers were recruited to undertake the survey work. The second survey was initiated in 2009 and ran for 18 months with the same team being present. However, only 91 of the original companies were still in operation. The same methods and approach to the survey work was undertaken in both cases.

The manufacturing SMEs were identified from their UK Standard Industry Classification codes (SICs) and a range of manufacturing sectors were targeted. Companies were considered SMEs against the appropriate definition for SME categorisation at the time of the survey (turnover, No of employees, ownership profiles etc). Table 1 shows the number of SMEs assessed per industrial sector. The table also shows the number of companies by size, which fall into each industrial sector area. The industrial sectors were pre-defined under the terms of funding and were considered to be the high value industrial sectors within the UK. The table also shows the number of SMEs in each category which were considered Original Equipment Manufacturers (OEMs). All other SMEs were considered to provide sub-contract services to customers at tier one or two in their respective supply chains.

Table 1: The Number of Companies Assessed by Industrial Sector and Company Size

Size of SME (Staff Employed)	Industrial Sectors				
	Aerospace	Automotive	Medical	Electronics	Construction
1-50	2	12	3	8	5
51-150	6	10	8	12	13
150-250	2	8	3	2	2
TOTALS	10	30	14	22	20

Triangulation of the survey data was achieved through direct observation at the company premises as well as interviews with key personnel within the organisations. The same questionnaire was used by the project team for the both surveys in order to ensure consistency of results and analysis. Partly quantitative and partly qualitative the questionnaire captured specific company performance data whilst allowing a section for open answers by the respondents so that maximum information could be drawn from each company. The researchers aimed at senior level managers and in most cases the Managing Directors of the SMEs in order to draw from them their strategic opinions and thoughts on LSS Implementation and whether it was relevant for their companies to develop LSS strategies. As well as capturing the level and extent of LSS adoption and use, the questionnaire also covered the following quantitative data: Financial data – turnover, materials and labour costs, growth profile, operating costs, investment in BPI and experience of previous BPI initiatives over the past five years. Company profile –number of employees, direct and indirect staffing ratios. The questionnaire also captured the following qualitative data: Business type; Attitude to BPI; Attitude to Developing Business; Operational & Business Processes; Skills and Knowledge Base; Drivers and stimulators for LSS Implementation.

From the questionnaire feedback, the team were able to assess the information and start to identify a coherent assessment process for the data obtained. In this case the project team broke the feedback into three areas of investigation namely; Business Type, Lean Six Sigma activity and performance characteristics. Considering these three main sets of characteristics allowed the survey to demonstrate the correlation between the LSS activities being implemented and how the activities were affected by the commercial pressures and business strategies and systems that exist within SMEs. A simple classification system was developed; this is shown in Table 2. Here the table classifies the responses by providing a numerical grade of 1-3 to the responses to the questions. Classification in this way allowed for quick and effective report calls and data analysis. Calculating the modal values for the data sets allowed for overall categorisation of the companies. The initial analysis of the survey data showed that the SMEs could be split into three distinct categories each having specific characteristics when measured against the assessment criteria (modal values of 1 = Category C, Modal values of 2 = Category B etc).

Table 2 Grading Criteria for Questionnaire Data

Quantitative Response Key		Qualitative Response Key
Company Turnover (£)	Growth Profile	1 = Negative Response
1 = <500,000	1 = Declining	Little/No Knowledge
2 = >500,000 < 1500000	2 = Stagnation (some growth)	Little / No Experience
3 = > 1500000	3 = Growing	Little / No Interest
Labour Costs	Operating Costs	Poor / Non existent
1 = <25% of product cost	1 = <25% of Turnover	2 = Normative Response
2 = >25% <50% of product cost	2 = >25 <50% of T/O	Some Knowledge
3 = > 50% of product cost	3 = > 50% of T/O	Some Experience
Material Costs	R+D Investment	Some Application/Inconsistent
1 = <25% of product cost	1 = <25% of Turnover	Could be improved
2 = >25% <50% of product cost	2 = >25 <50% of T/O	3 = Positive Response
3 = > 50% of product cost	3 = > 50% of T/O	Excellent Knowledge/Experience
		High Levels of Interest
		Excellent application
		Excellence

3 SURVEY RESULTS AND ANALYSIS

The initial survey of 2006-2008 concluded that SMEs fell into three distinct categories of LSS implementation. Just over 11% of SMEs were highly advanced in their approach to the implementation and use of LSS and had developed robust and responsive business systems based upon a continuous culture of business process improvement. These companies were termed Category C companies and were generally seen as higher performing companies which primarily worked successfully in the automotive supply chain. Likewise, just under 64% of SMEs did not implement LSS and these were termed Category A companies. It was however in the central category those termed Category B that some 25% of companies aspired to implement LSS but believed that they had neither the technical capabilities of human resources to drive such initiatives to their full potential although some significant LSS work was being done in this category. This is where the second survey concentrates upon in order to ascertain primarily whether the Category B companies had actually migrated towards the greater implementation of LSS. Likewise, the second survey also investigates whether some of the Category A companies had actually started to move towards greater LSS development.

Through observing the performance and operating mechanisms of Category A companies, it was seen in most cases that company performance was improved as a result of an effective combination of appropriate information, product design and production technologies in order to create a high quality, cost-effective, rapid-responsive, flexible and productive manufacturing environment and that LSS was used to ensure that the functioning and interconnections between these production elements were kept at their optimal level of functionality. However, in reality many of the companies surveyed incorporated only one or possibly two of these elements into their company operations and as such, LSS was used as an isolated business improvement approach in either product design (through DFSS) or on the traditional production environment. Therefore, SME categorisation included the need to identify the 'amount' and level of production integration in companies. As with the previous survey, it was observed that in general, Category C companies were significantly more profitable and produced higher value products for the industrial sectors in which they supplied. It was observed that in these companies, they did not necessarily employ more staff but in many cases the LSS allowed the company to achieve higher outputs with less staff hence contributing to greater profitability. In general there was no movement of Category A companies migrating successfully Category C but a small movement of Category B companies moving into the Category C was observed.

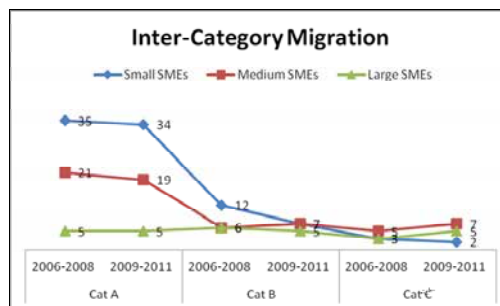


Figure 1: Composite graph of Inter-Category Migration

The results of the inter-category migration are shown in Figure 1. The number of companies that existed in the 2009-2011 survey had dropped by 5 from the previous survey (96 in 2006-2008 to 91 in 2009-2011). It is important to note here that whilst it could be considered that 5 companies had ceased trading within survey cycle, this is not entirely the case. Company failure which was observed by cessation of trading occurred in 2 Category A companies and 2 Category B companies. The remaining company was a Category C company who was bought out as part of a manufacturing group and hence ceased to be SMEs. In general, the loss of 4 companies from the 96 initially surveyed is seen as highly positive considering the economic climate and suggests that the Category A companies

especially, showed high levels of resilience to the tough economic even though they showed very little interest in implementing LSS. Therefore, there is possibly another set of factors that explain the ability of these companies to ‘weather’ the economic downturn and effective LSS implementation has little or no effect on their ability to survive.

3.1 INTRA-CATEGORY MIGRATION

In addition to the three fundamental categories identified, the second survey investigated the intra-category migration that occurred in the survey companies. Intra-category migration aims to identify the companies who continued to develop and advance the LSS methodology but had not developed their expertise to a level that meant they were able to move in to the higher category (i.e from B to C for example). The grading approach shown in Table 2 was used again to measure the migration within the category on the basis of observing the application and implementation of the LSS tools and techniques on a ‘little’, ‘some’ or ‘good’ grading. This migration analysis provided much needed new information on the dynamical nature of LSS development in companies. Figure 2 provides a graphical representation of the intra-category migration. The findings from this work are shown below:

- 15% of companies migrated from Category A towards Category B. These Category A companies had by the time of the second survey, realised that survival of the business may rely on adoption of improvement methodologies such as LSS, to prevent competition from low cost economies and increased local competition and as such were starting to develop basic LSS methods and tools.
- Category B companies migrating towards Category C totalled only 11% (1 company). These companies were considered to have made the transition toward forward-planning of LSS development with a view to leading the market and ensuring sustainability of the business.
- The survey did not find any appreciable development or enhancement of the LSS methodology in companies considered to be in Category C in this survey. This does not suggest that the companies could not improve but rather indicated a more worrying trend that little or no innovation was taking place to extend or enhance LSS in their business processes and systems. Figure 2 shows graphically the intra-company migration profiles of Category A and B companies.

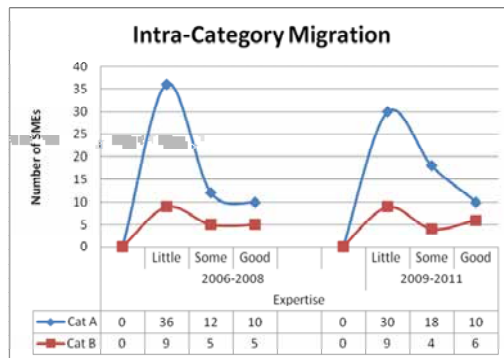


Figure 2: Composite graph of Intra-Category Migration

4 CONCLUSIONS AND RECOMMENDATIONS

In general the migration of SMEs towards LSS implementation is relatively static over the four survey cycle. Only small shifts of companies are seen from one category type to the other. However, in more specific terms the larger SMEs were seen as being more likely to transfer across category boundaries.

More specifically, when focusing on the research objectives set at the start of this paper, the following results were obtained;

Q1. Are we able to identify whether the rate of LSS implementation in manufacturing SMEs has grown between the two survey periods and hence establish whether the recession had forced companies to employ LSS to increase operational performance?

No evidence was found to support the fact that the recession had increased company awareness of the need to adopt LSS in order to reduce waste and hence operational costs. With only an average 4-6% of companies migrating across the category boundaries, the statistical evidence supports the qualitative analysis that the adoption of LSS has been poor. In fact, the actual number of companies falling in to Category A (little or no adoption of LSS) had remained static over the survey period.

Q2 Are we able to identify whether SMEs have continued to increase the use of LSS in their respective companies and have therefore migrated towards being experts in LSS application?

Yes, the team observed more intra-category migration (increased activity within each category without moving across the categories) of approximately 13% on average in each of the cases. This suggests that LSS is being developed and implemented more but progress is still quite slow

To extend the issue highlighted in Question 2, the important finding from this programme of work was seen when analysing the intra-category migration. It was observed that a high degree of intra-category movement was observed in both Category A & B companies although no development and enhancement was seen in Category C companies. Some 13% on average of companies within these categories had shown significant development of their LSS systems and were well on their way towards category boundaries. These companies showed distinct migration from their previous position but have not made the jump in to the next category for a number of reasons (LSS not being fully developed, internal manufacturing systems not being fully synchronized etc.). Of the companies who had implemented LSS it was clear that the need for such implementation was driven by their customers rather than an internal decision from within the company. Therefore, the survey showed that most LSS adopters also primarily worked within the automotive supply chains.

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MADE TO SERVE: A MODEL OF THE OPERATIONS PRACTICES AND TECHNOLOGIES THAT DELIVER SERVITIZATION

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ABSTRACT

This paper explores how successfully servitised manufacturers deliver advanced services and proposes a model that describes how they configure their operations. A case study methodology is applied across four manufacturing organisations successful in delivering advanced services. A descriptive model is then formed based around six popular technologies and practices.

Keywords: Servitization, Product-service systems, case study.

1 INTRODUCTION

Servitization is the process of transforming manufacturers to compete through Product-Service Systems (PSS). The commercial and environmental benefits of PSSs are compelling and well documented; Rolls-Royce earning over 50% of their revenue from services is cited almost to exhaustion. But below the economic success stories of large multinational companies, what does it really take for a manufacturer to succeed through a servitization?

Advanced services are a special case in servitization. Sometimes known as capability or availability contracts, here the manufacturer delivers services (coupled with incentivized contracting mechanism) that are critical to their customer's core business processes (i.e.: Power-by-the-hour). Successful delivery of such services demands particular organisational principles and relationships which differ to those applied in production operations (Chase and Garvin, 1989; Oliva and Kallenberg, 2003). A lack of the necessary capabilities within operations explains why some manufacturers fail to realise the anticipated benefits of servitization. The research described in this paper has therefore set out to question: *What are the distinctive practices and technologies, within the broader operations of servitized manufacturers, which are employed to successfully deliver advanced services?*

In this study we have investigated four manufacturing organisations that are leaders in the delivery of advanced services. In each, data has been collected across the organisation, service-delivery partners, and key customers. Analyses has then identified the popular technologies and practices used within their operations, and then used this understanding to create a descriptive model that helps to explain their adoption. This model summarises how these practices and technologies combine to provide the key capabilities that underpin the successful delivery of an advanced services offering.

2 METHODOLOGY

This study set out to build our understanding of how the operations of manufacturers are impacted as they servitize. In particular, to extend our understand of *What* practices and technologies are commonly deployed by successful organisations, and also better explain *how* and *why* these combine to deliver advanced services. The exploratory work of Baines *et al.* (2009) offered a valuable starting point.

The propositions in this earlier paper are a synthesis of both production and services operations literature. Consequently they provide the basis for a comprehensive set of ‘guiding questions’ to orchestrate data collection around ‘why’ and ‘how’ practices and technologies support the delivery of advanced services. Also, this earlier study found that a case study methodology was invaluable for exploring and gaining insight into the detailed workings of an organisation and so a case study methodology was again favored.

Critical to the success of this study was the identification and engagement of manufacturers that had a demonstrable record of successful delivery of advanced services. Financial success was considered within a broad set of indicators. These included citations from other researchers (i.e., references made in publications), indicators of innovation (i.e., patents registered), and general reputation within the business community for delivering advanced services (i.e., conversations with practitioners).

A short-list of companies was formed and prioritised, and then companies were approached in that order. This relied on informal networks for introductions to key personnel. During the process, care was taken to avoid approaching competing companies since this would inhibit willingness to participate. In all, four cases were identified and preliminarily engaged by mid-2009; they were visited, and negotiations concerning access and confidentiality were undertaken. All cases were in progress by early 2010. On average, it took 18 months to complete each case study. A data collection protocol was developed as guiding questions around the work of Baines *et al.* (2009) In particular data was collected for (1) the typical characteristics of the service offering and (2) the technologies and practices popular across the case companies.

Analyses sought to identify from the data those practice and technologies that are common to all the cases, to explain these, and to understand how they supported advanced services. Systematically we examined the records of each interview, identified the practices and technologies being discussed, and captured these as branches of the mind-map. As each set of additional data was added, the mind-map was adjusted (eg: branches were grouped together), and broad themes began to emerge. The mind-maps for all four cases were then compared and combined.

The results themselves are in two parts, the first dealing with the characteristics of the advanced service offering and the second summarising the popular practices and technologies exhibited within the operations of the case companies. Six policy areas have been directly derived through the analysis. They represent the six areas where the practices and technologies at the case companies commonly differed to those in production.

3 DISCUSSION OF RESULTS

In this section we examine the practices and technologies for each policy area, and rationalise how these impact the successful delivery of an advanced service.

Performance measurement: Measures in the delivery of advanced services focus on outcomes aligned to individual customers, which are then cascaded in (1) customer facing measures, (2) internal macro-measures, and (3) localised measures of contract fulfilment. The manufactures translate these customer facing measures into their own internal metrics. These are then further deconstructed into local measures and indicators. These are used by the manufacturer to control all the sub-processes involved in the management of service delivery. For example, they may capture the number of faults recorded on a train or aircraft between scheduled maintenance activities. Alternatively, these might be standard times for carrying out maintenance activities, and indicators such as variance from these times.

Facilities and their location: In all cases the delivery of advanced services is accompanied by the manufacturer developing or adopt facilities, co-located and distributed throughout customers operations’. This practice was given to exist for two principal reasons: (1) localised facilities enable faster fault diagnostics and rectification. Largely because staff are physically closer and more likely to be available when a failure occurs, possibly witnessing an incident, and taking corrective actions more quickly and precisely; and (2) localised facilities sustain strong relationships between the manufacturer and customers at the level of day-to-day operations.

Micro-vertical integration and supplier relationships: As expected, all our servitized manufacturers have extended their operations forwards, to undertake a range of activities such as condition monitoring, maintenance, repair, overhaul and management of their own products on behalf of their customers. In all cases there is also clear retention of design and production capabilities to support services deployment (rather than product manufacture). These activities are under the direct control of the business function that holds the responsibility for supporting services (sometimes referred to as the front-office).

Such micro-vertical integration occurred across all the cases and was given to exist because it enables: (1) reduced exposure to excessive stockholding delays and costs from acquiring components remanufactured in the supply chain; (2) components can be more easily redesigned, removing design flaws, and so reducing chances of future failures and associated costs; and (3) a route for transferring good practices developed in production into service operations (e.g., case 1 exploits Lean techniques through-out their service operations, and the route for this has been through their earlier adoption within the production operations of this organisation).

Information and communication technologies: Across our case companies there was a common architecture for such ICT systems. Such ICT provide remote insight into the condition and use of a product, and advanced warning of impending failures. For example, all cases use ICT systems to register and diagnose faults on their products, and use the information to schedule preventive maintenance. Cases 1, 2, and 3 incorporate in these systems a GPS capability which provides information on product location. These are mobile assets, and much time is saved by knowing where they are located when a fault occurs. Cases 2 & 3 also gain significant value from knowing how their products are being used by customers. This information is used for: (1) contract monitoring (eg: monthly negotiations about equipment usage); (2) to enhance productivity and reliability (eg: Incentivise and guide operator training so reducing consumables such as fuels and tyres); and (3) ultimately feed through to the design process for future products.

People deployment and their skills: Our investigation focused largely on skill-sets that underpin the 'behavior' of the people in the front-line of service delivery. Analysis and synthesis of our case data using mind-mapping techniques led us to identify six principal behaviors that collectively led to a positive customer experience and the skill-sets that underpinned these, namely; (1) flexibility, (2) relationship-building, (3) service-centricity, (4) authenticity, (5) technical adeptness, and (6) resilience. The justification given for these skills is that they facilitate and sustain positive relationships with customers. However, the extent to which these skills are demanded of individual staff does vary according to role. For example, a Condition Monitoring technician will need stronger technical skills relative to an Account Sales Manager, who will correspondingly need to be stronger at relationship building.

Business processes and customer relationships: Our cases revealed that processes are integrated into a wide range of customer 'touch-points', and set out to be proactive in the way they deal with issues. With advanced services processes are formed to deliver desired outcomes from products. At the outset of the contract, policies are established which agree the condition of the product and the actions necessary to maintain these. The interactions between the customer and manufacturer are then around communication rather than negotiating an action. Here, the customer will be informed so that contingencies can be executed. The outcome of the whole process is that the product is returned to be available for use rather than simply repaired. The manufacturer is incentivised to achieve this by penalties associated with the customer facing performance measures. In the example above, where the truck is not available for use, the manufacturer will be penalized.

4 MODEL OF THE DELIVERY SYSTEM FOR ADVANCED SERVICES

The popular practices and technologies only go part way to explaining the operations that case companies put in place to deliver advanced services. These act as a system, *interacting* with each other, to collectively provide the manufacturers with the *capabilities* to successfully deliver the

desired advanced service. Our analysis has enabled a model to be created that captures the principle structure of this system (see Appendix 1). This shows how the generic characteristics of an advanced service are supported by the practices and technologies in each of the six policy areas. This linkage is explained by introducing two *foundational capabilities* and, also, the mediating factors across the system. The elements of this model are as follows.

Foundational capabilities: There are two capabilities that underpin the successful delivery of advanced services. Running through our findings are two particular capabilities; (1) An ability to respond cost effectively, and (2) An ability to improve cost effectiveness.

Many of the practices we have presented enable the manufacturer to respond. Case 1 illustrates this well. They are penalised financially by their customers if their high-speed trains are unavailable, unreliable, or do not perform to standard. Responsiveness is key. Case 1 has developed the people, systems and processes to ensure any failures are dealt with rapidly, and indeed proactively, so the customer experience is unaffected. The same is true for Rolls-Royce holding a Power-by-the-hour contract with Singapore Airlines, or Xerox providing printing capability for Reuters.

In addition, the capability to improve designs and systems begins to explain why manufacturing organisations, with their design and production expertise, are well suited to deliver advanced services. The driving motivation, here, appears to be a desire to improve the financial productivity of an advanced services contract once operational. Improvements can be made to both products and processes. Products can be re-designed so that they are more reliable, easier to maintain, and faster to repair should they fail. Similarly, processes can be re-designed to deal better with failures, ensure a rapid response, and minimise the manpower and materials necessary should a failure occur. Overall, the extent to which an organisation holds these capabilities begins to suggest how successful they are likely to be in delivering advanced services. Those that have both the knowledge and capacity as an organisation to be responsive, whilst also being able to improving their efficiency in delivering their response, are likely to be most successful. These underlying capabilities perhaps indicate the DNA of successful servitization.

System interactions: Many of our findings suggest such connectivity, for instance the need for facilities to be co-located with customer operations is affected by ICT capabilities and vice versa.

While all these cases exhibited this connectivity, the extent to which practices and technologies were adopted did vary. For example, case 3 is sophisticated with its use of ICTs; in some instances having as many as 200 sensors on vehicles and significant investments in prognostics. By contrast, case 1 has a lesser ICT capability to monitor high-speed trains, but here maintenance and repair facilities are more extensive.

A dynamic (time dependent) interplay occurs across all the factors given in Figure 2. Advanced services are adopted, in part, by customers who want to avoid the negative outcomes associated with an asset failing to perform its service. Since such responsibilities are taken on by the manufacturer, there is a natural incentive to create designs that are more reliable and easier to maintain. Consequently, this relaxes the motivation for the customer to adopt such services.

This is apparent, for example, with case 4 in which the asset has the capability to conduct self-diagnoses and healing, along with a modular design that enables faulty sub-systems to be replaced easily in the field. As a consequence, case 4 engages in the least sophisticated services contracts, practices and technologies. As this trend continues and equipment becomes more reliable, it is likely to be more difficult to sell services. This cycle is perhaps, only disputed when a new technology is introduced that offers advances in performance, but its newness also increases the risk of failure.

The extent to which a physical presence is needed is relaxed by a number of factors. Case 4 has a policy of modular equipment design with built-in back-up systems. These modules are relatively small and portable, and information and communication technologies are used to remotely diagnose problems and chose corrective actions. This built-in redundancy, portability and remote monitoring, means that a maintenance technician can cover several customer sites from a single maintenance hub.

The extent of this micro-vertical integration is moderated by a range of factors. This 'tail' of design and production activities appears shorter where strong links exist with a production facility and partners in the supply-base. Highly significant across all cases was the contractual relationship with these suppliers. Integration is relaxed where suppliers are willing and able to provide capabilities, that

mirror the commitments given by the servitized manufacturer to their customers. Likewise, this integration is less for lower-value sub-systems where stock-holding is more affordable.

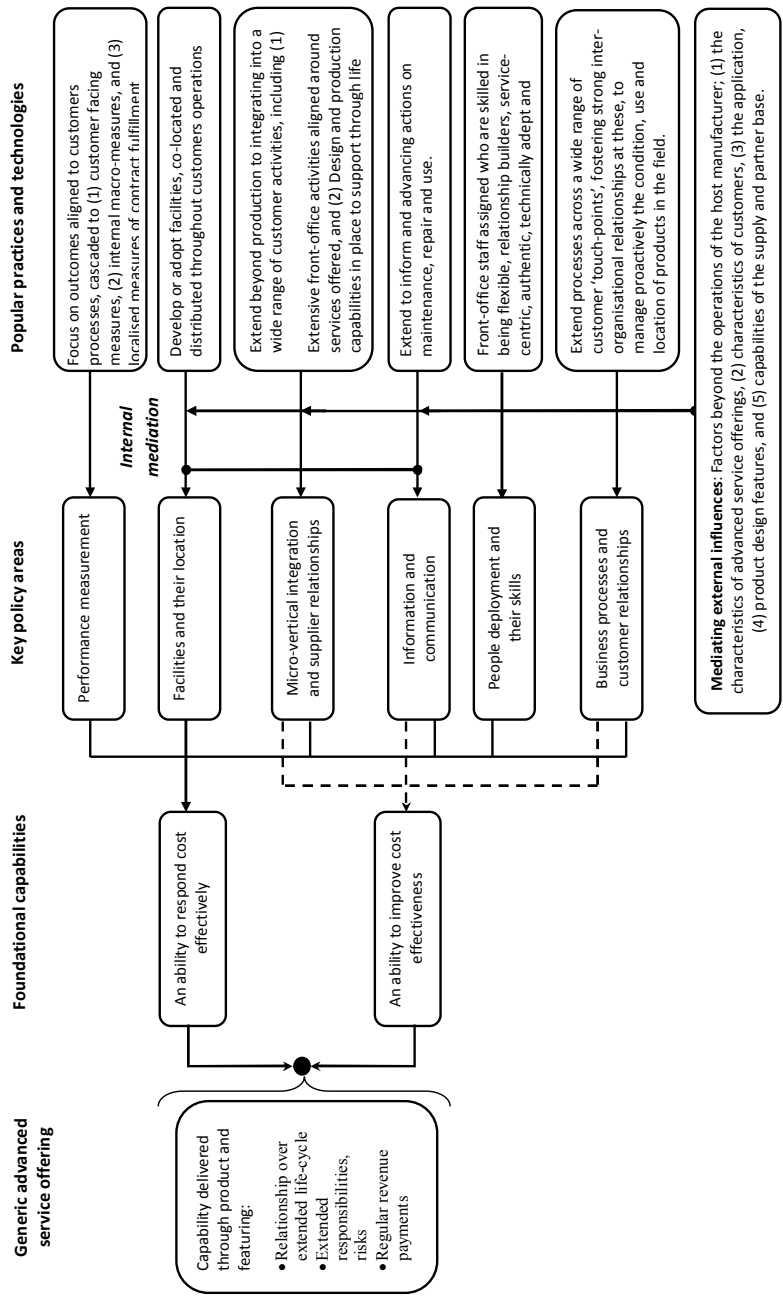
The sophistication of ICT capabilities is relaxed by a number of factors that help to reduce risk exposure, in particular: (1) assets are stationary and so don't require tracking; (2) the proximity of the manufacturers facilities enable manual observation to be easily carried-out; (3) there are built-in back-up systems; and (4) there is easy access of conventional communication channels such as the Internet.

5 CONCLUSIONS AND FUTURE WORK

This paper contributes to both the theory and practice of servitization. It explains that the successful delivery of advanced services is achieved by a tightly coupled delivery system that features; (1) facilities that are collocated and distributed throughout customers operations, (2) integrated both forwards and backwards in their supply chains, and (3) staffed by personnel who are flexible, relationship-builders, service-centric, authentic, technically adept, and resilient. These people work with, (4) business processes that are integrated into their customer's operations, (5) supported by Information and Communication Technologies that enable remote product monitoring, with (6) the entire system being controlled by measures that reflect outcomes aligned to individual customers, and then cascaded down into various forms throughout the service delivery system.

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Appendix 1: Advanced services delivery

DELIVERY MANAGEMENT OF INDUSTRIAL PRODUCT-SERVICE SYSTEMS – CHALLENGES FOR A PERFORMANCE MEASUREMENT

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ABSTRACT

In the manufacturing industry, competitors are continuously struggling to differentiate themselves from other companies in the market. Industrial product-service systems (IPS²) offer this differentiation by representing a paradigm shift from traditional product selling and service offering to providing customer value. During the use phase of IPS², the organisation and planning are executed and managed by the IPS² execution system (IPS²-ES). To ensure and improve the effectiveness and efficiency of the IPS²-ES during the use phase, a performance measurement is needed. This paper presents a motivation for a performance measurement during the delivery phase and based on this the requirements for the performance measurement are introduced. An outlook for further research will be given.

Keywords: Performance measurement, industrial product-service system (IPS²), planning

1 INTRODUCTION

For several years now, product-service systems (PSS) have been in the focus of both research and industry, as for example presented in Aurich and Clement (2010) and Mont (2002). The authors point out that PSS consist of product shares and service shares that are provided to a customer to achieve customer value. Meier *et al.* (2010) also cover the topic of integrated products and services, but they focus on industrial product-service systems (IPS²) with customers from various industry sectors, not on consumer solutions. A definition of IPS² is presented in Meier *et al.* (2010) as follows:

An Industrial Product-Service System is characterized by the integrated and mutually determined planning, development, provision and use of product and service shares including its immanent software components in Business-to-Business applications and represents a knowledge-intensive socio-technical system.

Research shows that the lifecycle of IPS² consists of different phases (Aurich *et al.* 2007; Meier *et al.* 2012). While Aurich *et al.* (2007) list those phases as organisational implementation, PSS planning, PSS design and PSS realisation; Rese *et al.* (2012) present a more detailed approach. They distinguish between a planning phase, development phase, implementation phase, delivery and use phase and a closure phase. This paper focuses on the delivery and use phase, in which the IPS² is used by the customer or the provider to fulfil the customer needs. To be able to deliver the IPS² to reach the contracted customer value, the provider has to work in networks, as for example suggested in Völker (2012). Although there are several contributions for supply chains in different sectors (e.g. Voudouris

et al. 2008) the network organisation for IPS² has special requirements and is briefly explained in section 2.1. For the efficient and effective delivery of the IPS², the resources that are provided by the different network partners have to be planned. Both strategic capacity planning as well as operational resource planning have to be considered (Funke 2012). These research fields are briefly described in section 2.2. Because of the complexity of these planning approaches and the need for managing the network of partners, it has been found that existing software solutions do not provide the required support for the IPS² provider (Meier and Dorka 2013). This paper introduces a new software system, named IPS² execution system, which is further described in section 2.3. Based on the state of the art in this field, this paper demonstrates the need for a performance measurement method for IPS² in chapter 3. Based on this motivation, the requirements for such a method are derived in chapter 4. The results of this work have laid the basis for further research, which is presented in an outlook at the end of this paper.

2 STATE OF THE ART

To give an introduction to the research topic, the network organisation and planning for IPS² are described in the following sections. The IPS² execution system is explained, which sets the context for the performance measurement presented in this paper. In this context, the authors provide an overview of the literature concerning performance measurement and present different views on the topic.

2.1 Network Organisation for IPS²

The delivery of IPS² is a complex task. An IPS² provider cannot necessarily provide all required resources for the delivery. Therefore, a network of partners, including the IPS² provider and the IPS² customer, is created to deliver the IPS² in cooperation (Völker 2012). The integration of the customer is above all an important task in product-service systems. Each partner in the network assigns some of his resources to be available for the delivery and by that forms a virtual organisation unit. The different virtual organisation units in the network form a virtual organisation for the delivery of IPS² (Völker 2012). While the different partners can even participate in the development of the IPS², the IPS² provider is responsible to select the partners who form the network for the delivery.

2.2 Planning for IPS²

Based on the network organisation for IPS², the resources provided by the network partners need to be planned for the delivery of the IPS² customer value (Funke 2012). Multiple delivery processes (e.g. maintenance processes, training events, repair processes, etc.) per IPS² have to be scheduled. Most delivery processes can be considered in the strategic capacity planning because their schedule is predefined in the IPS² product model. Here the required capacities for different resource types are identified. During the execution of the delivery plan it might happen that an unscheduled process has to be executed, as for example a repair process. Operational resource planning integrates the new process into the existing delivery plan using the available resources.

2.3 IPS² execution system

To support an IPS² provider in the delivery of the IPS², namely in the scheduling of delivery processes and management of the partner network, an IPS²-ES can be utilised (Völker 2012). A definition of an IPS²-ES is given in Meier *et al.* (2013) as follows:

An IPS² execution system is the essential software system for the IPS² operation phase that supports the IPS² provider in the provision of customer value by adaptive IPS² delivery planning, IPS² network management and an integrated performance measurement method.

According to this definition, the IPS²-ES has to provide means of adaptive IPS² delivery planning and IPS² network management. To do this, it has to leverage methods developed for IPS² and provide proper software support. Basically, the organisational entities of the IPS² network have to be represented in the software system to provide data about resources that they provide for the IPS² delivery (Meier *et al.* 2013a). With this information the IPS²-ES can execute strategic capacity planning and operational resource planning as introduced in the chapter above. Whenever an unplanned demand at one of the supplied IPS² arises, the IPS²-ES has to consider this demand and

change the delivery schedule to include the new demand. The IPS²-ES provides a high level of automation in the execution of its tasks. It uses self-organisation to add or remove connections to the partners' software systems and executes the planning method automatically whenever needed (Meier *et al.* 2012). Although the user of the system can intervene at any time and change the systems behaviour, the following questions remain unanswered: is the intended effect of the IPS² reached and is it reached efficiently? This means that the performance of the system is not known. Since the IPS² operates automatically and does so without requiring user input, it is not possible for the user to evaluate the performance based on his actions. A measurement of the performance, which is already mentioned in the definition of the IPS²-ES, can provide the required information to decide whether a user intervention is needed.

2.4 Performance Measurement

Performance Measurement approaches have been used for corporate management since the end of the 1980s. These approaches use new concepts and key figures (Gleich 2001) and are a further development of traditional ratio systems (Leimeister 2012). Compared to control data which refers to the past in traditional ratio systems, Performance Measurement is designed to be future- and process-oriented (Lynch and Cross 1995). This development was pushed by the interest in process orientation, customer orientation and quality improvement (Giese 2012). Hence, performance measurement has not only been applied for monitoring and measuring but also as a decision making support. Literally, Performance Measurement means the measuring of performance. There is no common definition of Performance Measurement in the specialist literature because many authors forgo a definition due to the high complexity and permanent development (Giese 2012, Leimeister 2012). However, the most definitions have in common that performance measurement should control and improve efficiency and effectiveness and the focus is on strategic issues (Giese 2012). Another reason for the no common definition of performance measurement is that performance measurement is used in different sectors such as supply chain management (e.g. Giese 2012) or services (e.g. Leimeister 2012). Richter and Steven (2009) developed a balanced scorecard as an instrument of performance measurement for IPS². The classic balanced scorecard from Kaplan and Norton (1997) considers the process, potential, customer and finance perspective. The balanced scorecard for IPS² was extended by the relationship perspective because IPS² require trustful dealings between the partners. The focus of the IPS² balanced Scorecard is rather on strategic issues. Computer science uses a similar definition. Performance is defined as a "degree to which a software system or component meets its objectives for timeliness" (Smith 2002). That means primary response time behaviour and secondary throughput and capacity of the software system (Pressmann 1992). The response time behaviour is an index for the speed of the system from the end user perspective (Smith and Williams 2001). The throughput describes the operations per time unit (Woodside 1988). The capacity of the software system is defined as the collection of resources like the speed of the processor or the bandwidth of the network. Thereby the response time is the most important performance indicator for the end user. It is irrelevant for the end user whether the capacity or throughput is the problem for a high response time (Schlimm *et al.* 2007). Overall, performance measurement is a way to measure and evaluate the effectiveness and efficiency of a system in order to draw conclusions. It is of minor importance whether a company, a department or a software system is analysed. The primary function of a performance analysis is to support managers in making decisions.

3 MOTIVATION AND NECESSITY FOR AN IPS² PERFORMANCE MEASUREMENT METHOD

Referring to the chapter above, the main aim of the IPS² performance measurement method (IPS²-PMM) is to make sure that the targeted effect of the IPS²-ES is reached. As already described in the definition of the IPS²-ES, the system is a highly automated software system that provides IPS² delivery planning and coordination of the partner network. During the delivery of IPS², the needs of customer and provider have to be provided as defined during the IPS² development phase. Customer expects that the promised customer value is reached and that s/he is satisfied with the delivery of the IPS² as a whole. The provider, on the other hand, is interested in the efficient and effective delivery, represented by the delivery plan created by the IPS²-ES. In addition to that, the provider requires the

steady support of the IPS²-ES without major problems. The execution of the different tasks and the preservation of customer satisfaction as well as provider support are aggravated by the dynamic IPS² environment. Frequent changes in the customer demands require a quick reaction and flexibility of the IPS² provider and the IPS² itself. Thus IPS² are not rigidly developed but dynamic in their design. Particularly the cooperation with the customer allows for the quick reaction to changed customer requirements. Here the trigger could be the customer as well as new requirements which arise from generated knowledge during the use phase (Völker 2012). In addition to the dynamics represented by the customised IPS², each partner in the network and the IPS² are exposed to a general change which every company is confronted with. Examples for such a general change are developments like globalisation. These challenges are called change drivers and affect the whole organisation of a company (Wiendahl *et al.* 2007). Particularly service suppliers are exposed to a high uncertainty during the service delivery (Erkoyuncu *et al.* 2011). By the connection of several companies in supply chains, changes cause problems in the whole supply chain, as can be seen in the bullwhip effect (Lee *et al.* 1997). A similar effect is expected from changes within IPS². By the high number of stakeholders in IPS² networks, the effects of the change drivers on single companies are potentiated. As companies in IPS² networks originate from various industrial sectors, change drivers from all these sectors have an influence on the IPS² networks and therefore on the IPS² themselves. Hence, the delivery planning faces major challenges. The dynamics of IPS² modify the intended effect of the IPS² during the use phase which the planning has to adapt to. In turn, the main instrument for adapting the planning in the IPS²-ES is the weighting of the planning targets. A modified adjustment of these parameters leads to different planning results. Besides the planning, the network management is a main functionality of the IPS²-ES. From a traditional view, the competition of products is decisive for market leadership. However, with IPS² and the new product understanding, the qualities of the companies in the network are important sales arguments. Thus, a robust, effective and efficient network is particularly necessary. Here, especially the communication between the IPS² and the network partner is of high importance for the software system. Only a continuous communication with up-to-date information enables a feasible planning. If incorrect data is transferred or outdated data is forwarded, the danger of creating an invalid delivery plan is significantly rising. This prevents the network partners from reliably executing the delivery plan, which has a negative impact on the robustness of the network. As the IPS²-ES is a software system, it is subject to the same challenges that other software systems face. An IT measuring system can provide support in order to ensure a stable software environment. The motivations described above lead to the necessity for a method which safeguards the intended outcome of the IPS²-ES for an effective delivery of IPS². The special requirements for such a method will be presented in the next chapter.

4 REQUIREMENTS FOR AN IPS² PERFORMANCE MEASUREMENT METHOD

As described above, performance is a way to measure and evaluate the effectiveness and efficiency of a system in order to draw conclusions. In the context of the IPS²-ES, performance can therefore be defined as the capability of the system to execute the tasks required to effectively and efficiently deliver the IPS². These tasks are described in the definition of the IPS²-ES as follows: support the IPS² provider in the provision of customer value by an adaptive IPS² delivery planning, IPS² network management and an integrated IPS²-PMM. The IPS²-PMM ensures the performance of the other two main aims: IPS² delivery planning and IPS² network management.

In these systems, the technical side of the IPS²-ES can first be considered. For the overall system performance it is important that the leveraged software services (e.g. planning service, resource availability service, etc.) are executed without errors. Whenever a service shows a high error ratio, these errors might affect the whole IPS²-ES and therefore degrades its performance. Another indicator for under-performing services is the response time behaviour. A slow response time might either be caused by a sluggish network connection or by an inefficient algorithm used for the intended functionality. In both cases, the performance of other services or the IPS²-ES as a whole might suffer from these defects. It is not always possible to tell in which time a service has to answer a request, but it is possible to compare services with similar capabilities to each other. Hence, the IPS²-ES performance measurement has to provide a mechanism that allows the user of the system to identify under-performing services. This information can be used to replace these services by services with a

similar functionality but a more appropriate performance. The adequacy of purpose of services and partners is even more important for the IPS²-ES performance than the technical performance. The most crucial service of the system is the planning tool, i.e. a proper delivery plan. As mentioned above, the delivery plan has to be created while keeping costs low, processes on schedule and utilisation optimal. For the operational resource planning, the real-time capability of the planning method is of high importance. During the time constraint for the planning only the weights for cost, punctuality and utilisation optimisation can be changed for the planning. The aim of the IPS²-PMM here is to change the weights so that the costs still offer a profitable IPS² delivery for the provider while the punctuality and utilisation can be maximised in the given planning time. This is an on-going function the PMM has to provide so that the planning weights are adapted to the currently given delivery processes, available resources and IPS² to be provided. Thus, the PMM has to optimise the quality of the scheduling and control of the IPS²-ES. Other services can also be checked against their adequacy of purpose. In the IPS²-ES, services to determine the travel time and costs for service technicians are leveraged. This may include train operators, route planning services for cars, air carriers, etc. When one of these services always comprises higher travel costs and/or longer travel times, the service provider might not be adequate for the transport of the service technicians. This can happen, for example, if an IPS² provider only delivers IPS² in his vicinity. Similarly, services for the transport of tools and spare parts can be more or less adequate for the use in the IPS²-ES of a certain provider. Hence, the PMM can help to identify less useful services. When these are removed from the system, the delivery planning method has to consider fewer options when creating delivery plans. The delivery in a partner network requires reliable partners. If any delivery process scheduled by the IPS²-ES is not carried out correctly, the original plan loses its effect and therefore the IPS²-ES performance deteriorates. This can happen if a network partner delivers incorrect spare parts or does not achieve the required aim within the execution of a delivery process. Also an unachieved first-time-fix-rate can have an influence on the performance. These aspects have a direct or indirect impact on the customer satisfaction. Hence, the PMM has to track the difference between intended and actually reached effect of the delivery plan. Using this method, the IPS² provider can identify whether partners are reliable in their part of the delivery of the IPS². Apart from the reliability of the partners, their capability to participate in the virtual organisation of the IPS² provider can be measured. The partners have to stipulate the resources they can supply and the time at which these are available. The accuracy of the data as well as keeping it up-to-date is crucial. Whenever the availability of a resource changes, the IPS²-ES has to be notified to be able to consider the new availability in the planning. This ensures that each network partner can accept a newly generated delivery plan. If the availability information is not accurate, the partners might have to reject the delivery plan due to a lack of resources, which in turn requires a new planning run of the IPS²-ES. Hence, the ratio of rejected to accepted delivery plans reflects the capability of the partner to participate in the virtual organisation. This ratio can also be useful for the partner assessment whenever a reconfiguration of the IPS² network is necessary.

5 CONCLUSION AND OUTLOOK

In this paper, the necessity of a IPS²-PMM for IPS²-ES has been presented. It is clearly shown that the effectiveness and the efficiency of the IPS²-ES cannot be determined by the user without the aid of the system itself. The two main tasks of the IPS²-ES, namely the network management and IPS² delivery planning, have to be measured technically and their adequacy of purpose of both services and partners in the network. The next step is a software implementation of the IPS²-PMM into the IPS²-ES.

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CHALLENGES OF LEAN THINKING APPLICATION IN PRODUCT-SERVICE SYSTEM

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ABSTRACT

Lean thinking is claimed to be as important to services as it has been to manufacturing. However, there is yet a lack of empirical research examining the possibility of applying lean thinking in Product-Service System (PSS). This paper aims to bridge this gap by focusing on the challenges of applying lean thinking in PSS. To achieve this aim, twenty interviews were conducted with participants that have a good experience in lean implementation. Those participants are working in UK manufacturing companies that implement PSS. Also, a comprehensive review of the published literature was executed to achieve a depth understanding of the various challenges already identified by other researchers. The findings highlight a number of challenges that emerge during the application of lean thinking in PSS, among them: understanding of lean, limited communication and leadership, and defining waste.

Keywords: Lean thinking, Product-Service System, Challenges.

1 INTRODUCTION

Lean thinking was first introduced into the field of operations management in the well-known book by Womack and Jones called “The Machine that Changed the World” (Womack et al., 1990). Lean thinking can be considered as a methodology that has its origins in the Toyota Production System (TPS) and whose principal objective is to eliminate waste and inefficiency from production systems in order to reduce costs, improve quality and reliability, and speed up cycle times (Sohal, 1996; Standard and Davis, 1999; Taylor and Brunt, 2001; Liker, 2004). So the core idea of lean involves determining the value of any given process by distinguishing value added steps from non-value-added steps, and eliminating waste so that ultimately every step adds value to the process. Lean is most frequently associated with the elimination of seven important wastes which include (overproduction, defects, unnecessary inventory, inappropriate processing, transportation, waiting, and unnecessary motion) (Shah and Ward, 2007).

The literature on lean thinking centres mostly on the manufacturing sector and especially on the automotive industry where it started. But recently because of the possible benefits gained by applying lean, other types of sectors such as the services sector (insurance companies, banks and fast food restaurant) (Bowen and Youngdahl, 1998; Goland et al., 1998; Swank, 2003; Piercy and Rich, 2009; Delgado and Ferreria, 2010), public sector (NHS, court system and government councils) (Krings et al., 2006; Radnor et al., 2006; Esain et al., 2008; Zokaei et al., 2010) and education sector (William, 2010; Barroso et al., 2010; Radnor and Bucci, 2011) have recently taken up the concept of lean thinking and introduced to their own management activities. According to Womack et al., (2005) lean thinking is not a manufacturing tactic only, but a management strategy that is applicable to all

organizations because it has to do with improving processes. All organizations are composed of a series of processes, or sets of actions intended to create value for those who use them.

However, in the literature reviewed on lean thinking, there were a very limited number of empirical research studies of the applications of lean in PSS. So the aim of this paper is to capture the challenges of applying lean thinking in PSS.

2 RELATED RESEARCH

There is a long debate whether or not manufacturing and service operations can be managed based on the same concepts (Fitzsimmons & Fitzsimmons 1998). Some stress the significance of distinctive service features like, Grönroos (1990), who claimed that there are four basic characteristic that can be used to identify services:

- Services are more intangible.
- Services are activities or a series of activities rather than things.
- Services are at least to some extent produced and consumed simultaneously.
- The customer participates in the production process at least to some extent.

Also, Schlesinger and Heskett (1991) argued that services are unique in terms of customer involvement and labour intensity.

On the other hand there are many authors who argued that the distinctive features of services should not be an excuse for avoiding manufacturing concepts as a means of increasing the efficiency of service operations. For example Bowen and Youngdahl (1998) argued that lean ideas transfer well from manufacturing to services provided they were employed with minor alteration. Additionally Allway and Corbett (2002) claimed that lean principles can be applied to many service sector firms, with equally the impressive results achieved in the manufacturing sector. In 2006 Radnor asserted that lean is transferable to the public sector and can be used to develop more seamless processes, improve flow, reduce waste and develop an understanding of customer value. Radnor (2006) found that lean is a suitable methodology for improving performance and embedding a continuous improvement culture in the public sector. Similarly Swank (2003), Piercy and Rich (2009), Delgado and Ferrerira (2010) confirmed that lean approach can be applied to services.

There are some authors who suggested that services can benefit and gain the same advantages achieved through lean manufacturing, if the lean concept and tools are adapted and adjusted to cope with the organizational context. For example Johnston (1994) and Ahlstrom (2004) claimed that the principles of lean manufacturing can be applicable in service operations, but with contingencies.

3 RESEARCH METHODOLOGY

The research commenced with a literature review to understand and investigate the application of lean thinking in manufacturing and service industries. Subsequently, the research aimed to determine the challenges of applying lean in PSS. The main databases used were ProQuest, Scopus, Web of Knowledge, Science Direct, EBSCO, and Google Scholar.

Twenty interviews were conducted, each interview lasted between one hour to one hour and half. Participants were selected based on some criteria like: years of experience, relation to the business strategy and the degree of involvement in the service processes. Participants were invited by telephone call or email, explaining the aim and objectives of the study. Table 1 presents the job title of the participants.

Table 1: List of participants.

Participants	Job title
1	Chief executive Officer
2	Head of Aftersales Business Development
3	CRM Manger
4	Fleet & Retail sales Manager
5	Service Manger
6	GM Strategy and Marketing
7	European Deployment Manger Lean Six Sigma

8	Business improvement Manager
9	Service Manager
10	Quality Leader

All the participants are working in UK manufacturing companies in different industry sectors (Trucks and Bus, Transportation, Document Management, and Aerospace). These companies were selected, because they have good experience in implementing the concept of PSS. Questions asked in the interviews were devised so that they captured opinions and beliefs of the participants regarding the application of lean. This included their expectations and experience of applying lean thinking in PSS and the challenges that they faced during the implementation. Examples of questions asked in the questionnaire include:

- What are the types of services that manufacturers are offering?
- What would you describe as the main challenges when adopting lean in the process of providing services to customers?
- What are the factors contributing to the success of lean implementation in the process of providing services to customers?

The answers received during the interviews were classified and analysed in order to identify the challenges and the success factors.

4 RESULTS AND DISCUSSION

The data analysis resulted in discovering factors related to the challenges and barriers faced during the application of lean thinking in PSS as presented in Figure 1. This section captures and discuss these challenges.

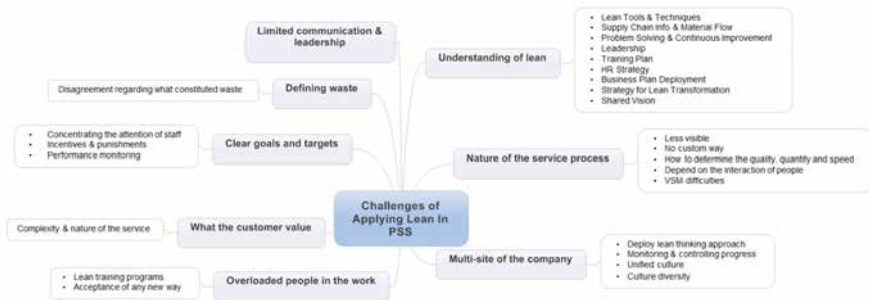


Figure 1: Challenges of applying lean in PSS

4.1 Understanding of lean

The answers of participants mentioned that the focus on efficiency gains have led to a number of partial implementations of lean as companies' managers have attempted to replicate the success of other without understanding the underlying principles of lean. According to Dunn, 2009 there are critical determinants that need to be put in place before organizations can embark on lean transformation. These determinants have been presented in Figure 1. At the top of the requirements are the tools and techniques, these are easily seen and readily available, thus they are often used for a quick fix. Unfortunately a through lean implementation requires all of the tasks from the bottom to the top for success. These include the development of a shared vision and an action plan. These vital components act as foundation to build on and therefore need to be carried out prior to the lean tools and techniques.

4.2 Limited communication and leadership

A major challenge for lean implementation was the observed lack of communication and leadership within the implementation phase. Changes to services which affect organizational operations need to be coordinated centrally and led from the top with a clear strategic framework to ensure it occurs systematically throughout an organization. In order for improvement to be sustainable staff must also be responsible for implementing solutions, with the full support of managers.

4.3 Defining waste

Lean thinking aims to identify waste to provide better services to customers (Westwood et al., 2006). Waste is any process that does not deliver value to the customer (Womack and Jones, 1996). From the data collected, participants defined waste as “tasks that do not add value to the customer or contribute to the efficient running of the services”.

Despite this agreed definition, participants indicate the difficulty of identifying waste. There were disagreements regarding what constituted waste.

4.4 Clear goals and targets

Central targets can be effective in concentrating the attention of staff on specific issues provided that the incentives and punishments are sufficient. However, poorly thought out targets deliver poor or perverse outcomes (Bevan and Hood, 2006; Appleby et al., 2005). Participants agreed that performance monitoring that is done badly can be harmful during the implementation phase.

4.5 Nature of the service process

The nature of the service process makes it harder to identify what needs to be changed and how to fix it where the service processes are less visible than the manufacturing processes. Manufacturing operations use a router to schedule the flow of materials through a process, so even the process has not been mapped there is still an awareness of process flow. On the other hand service processes have no custom around using routers so there is no way to know where any given piece of work is at any point in time. Moreover it is very difficult in the service processes to determine the quantity, quality, and speed required in the work. More than that, the service processes are more dependent on the interaction of people than are manufacturing processes. The nature of the service process made value stream mapping difficult since staff were unable to agree on a common approach for specific tasks. Participants agreed that demand on services is variable and unpredictable, where services varied immensely on daily basis based on the customers' needs.

4.6 Overloaded people in the work

Having too much to do with too little time to do it is a common perception in the workplace. This problem, often referred to as work overload.

There was an agreement that work overload can be one of the challenges during lean implementation. Overloaded people hinder staff to learn and accept any new way of doing the work. Although the work overload can hinder lean training programs and the degree of employee acceptance of the new approach.

4.7 Multi-site of companies

The wide spread of company makes it difficult to deploy the lean thinking approach throughout all the branches and also make it difficult to monitor and control the progress achieved in each branch. Wide spread companies also face the difficult task of developing a unified organizational culture and perspective. Cultural diversity is considered as one of the most important issues that a company can face in business because culture affects attitudes, approaches and perceptions of people and different cultures mean different attitudes, approaches and perceptions.

4.8 What customer value

The lean philosophy is founded on the concept of value to the customer (Young and McClean, 2008). Defining value may be simpler to achieve in industries such as manufacturing, where the customer is easily identifiable as the next person in the process (Young and McClean, 2008). However the complexity and the nature of the service process make it difficult to easily determine what the customer needs.

5 CONCLUSIONS

This paper captures the challenges of applying lean thinking in PSS. Previous research projects focused mainly on the application of lean thinking either on manufacturing industries (automotive, aerospace, furniture, electrical and electronic companies) or service industries (healthcare, airlines, insurance and banking). There is little or few studies that identify the challenges of applying lean in the process of providing services attached with a product. Based on the data collected from UK manufacturing companies the challenges of applying lean thinking in PSS can be: understanding of lean, limited communication and leadership, defining waste, clear goals and targets, nature of the service process, overloaded people in the workplace, multi-site of companies, and finally what customer value.

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INDUSTRY SURVEY REVIEW OF OBSOLESCENCE MANAGEMENT STRATEGIES IN PERFORMANCE BASED CONTRACTS

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ABSTRACT

This research study has been developed through a cross sectorial benchmarking survey and represents the development of a descriptive framework from a management strategy perspective. The survey is based on face to face interviews and a questionnaire about obsolescence and availability in defence and non defence sectors. The high research elements reported are related to the set of obsolescence factors and unavailability drivers identified, the availability modelling methodologies studied, and the categorization of obsolescence management strategies from suppliers to customer perspective reported. The main results presented in this research are the evolution of the state of the art of the availability modelling techniques, the justification of the lack of availability predictive tools based on a list of typical commercial tools applied in the industry today and the positive and negative outcomes of using commercial of the shelf (COTS) as design criteria in long life systems.

Keywords: Obsolescence Management Strategies, COTS, System Availability Modelling Techniques.

1 INTRODUCTION

The trend of the UK manufacturing Industry is currently moving from capability contracts to availability contracts based on service performance between the contractors and the final customer. The availability metrics as key indicators are the measurements of the performance of the product, service and systems contracted by the customers. One of the main challenges in the supportability of complex systems which consists of hundreds and thousands of components interconnected with different serial and parallel configurations is related to the predictability of the system performance. These high availability systems are impacted by the obsolescence issues delivering a critical behaviour. This makes the risk associated to the lack of fulfilment of the commercial agreement result in penalties and loss of benefits to the customer. Some of these risks are shared across the supply chain from the original equipment manufacturers (OEM), suppliers and the distributors to the first contractors. Today the customer's benefits from an industry business strategy perspective come from the management and optimisation of the sustainment processes and associated services more than the acquisition and management of the spares. The maintenance policies will be optimised based on the prediction of the failure rates and the control of the obsolescence management processes. It implies a better information collection and management control.

Obsolescence management is a key requirement in design, production, and maintenance during system operation and support stages. The obsolescence issues impact mainly on the system

supportability in terms of cost and the selection of the appropriate maintenance strategies. Due to the different Technology Maturity Levels and in order to avoid the consequences of the component/module obsolescence a mix of reactive and proactive mitigation strategies is taking place. Industry is focussing on the schedule and component availability optimisation to reduce the impact of the obsolescence event occurrences during the sequence of operation and support phases. Some of the related critical aspects are the availability optimisation of the spare parts in the inventory, the implementation of logistic strategies to decrease component lead times and the schedule of technology updates and upgrades at several points. It is also relevant the proactive mitigation strategies to avoid component degradation and capability reduction and the design strategies for obsolescence which could include system functionality improvements. The planning of active obsolescence management strategies rests in the fast technology evolution of electronic components, the lack of guarantee of suppliers and the continuous changes in environmental policies such as the “waste electrical and electronic equipment” WEEE or the restriction of Hazardous substance (ROHs). Therefor the obsolescence mitigation strategies will be focused on the impact reduction of the obsolescence issues on the availability of complex systems during the support and operational phases.

One of the benefits of this research paper is to help the managers of complex systems with the decision making process drafting a framework with the problems and potential solutions for the impact of the obsolescence on high availability systems. This study represents an insight review of critical operational research areas such as the reliability, availability, maintainability or logistics that is impacting on the systems performance in the industry today.

2 RESEARCH METHODOLOGY

This survey methodology is based on the sequence of activities shown in Figure 1.

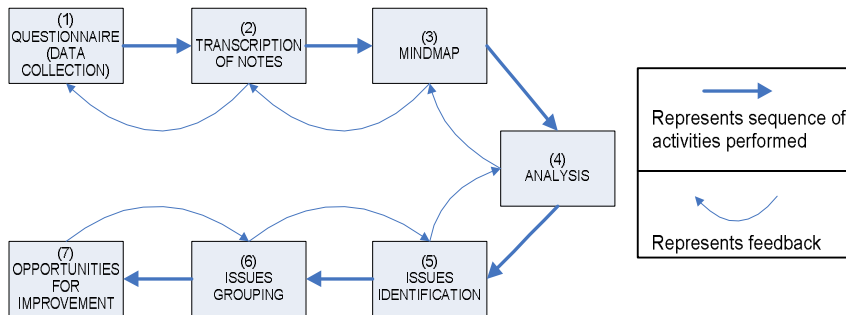


Figure 1: Research methodology of the cross sectorial benchmarking survey (Romero 2011).

This survey groups companies of Defence and non Defence sectors such as Railway, Aerospace, Marine or Power Generation. It develops more than 30 hours of face to face interview sessions and includes the participation of a total of 20 companies. Two main questionnaires about obsolescence issues and availability challenges have been answered by the industry. The results have been elaborated alongside with a literature review of the state of the art, which includes more than one hundred papers and reported to the companies participated.

3 OBSOLESCENCE MANAGEMENT STRATEGIES APPROACH

The obsolescence management activities can be classified into two different perspectives: the product life cycle approach based on the suppliers performance and the mix of proactive and reactive managerial approaches based on the resources and capability of the organisations which deliver the services contracted by the customer.

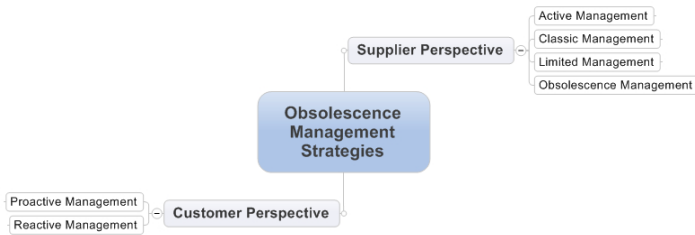


Figure 2: Obsolescence management strategies classification

The approaches showed in Figure 2 are described as follow:

1. Product Life Cycle Approach

It consists on four types of management strategies from supplier's perspective:

- a. Active management strategy: It is implemented when the items are fully sold and fully supported.
- b. Classic management strategy: It is implemented when the items are supported with spares and services.
- c. Limited management strategy: It is implemented when the spares and the supporting services are potentially available but are not guaranteed.
- d. Obsolescence management strategy: It is implemented when the spares, services and knowledge are not available and are not guaranteed.

2. Mix of Proactive/Reactive Management Approach:

It consists on two types of management strategies from operator's perspective:

- a. Proactive management strategy. Include several management activities such as:
 - Scheduling the updating and upgrading of systems.
 - Incentivising the supplier's chain to share the obsolescence risks.
 - Proactive Identification of obsolescence risk areas and components.
 - Periodic design reviews are in place.
- b. Reactive management strategy: Include several management activities such as:
 - Manual notifications.
 - Day to day obsolescence management tactics.
 - Obsolescence management plans based on suppliers' perspectives.
 - Component monitoring and marketing research.

Obsolescence events can be thought of as occurring at component and or system level. At component level the obsolescence of electronic components means the management strategies are focused on the logistics and management of inventory and how to improve component lead times under the constraint of the budget restrictions. Specific strategies include:

1. The periodic identification of the critical factors that contribute extending the lead time in supporting a specific component.
2. The obsolescence management planning and task scheduling for market research, component monitoring and acquisition processes.
3. The daily review tasks which include testing and integration of components in the equipment.
4. The process of identifying a list of critical obsolescence components for risk evaluations to reduce the number of potential obsolescence events.
5. Justification and prioritisation of the mitigation actions for each obsolete component based on cost-benefit comparison.

At subsystem/system level the obsolescence and availability management processes are focussed on the scheduling of technology insertions and different engineering aspects.

4 DESIGN FOR OBSOLESCENCE: COTS APPLICATION STUDY

Design for obsolescence in the actual system represents one of the main challenges in obsolescence management and implies the use of commercial off the shelf COTs solutions. Some of the relevant characteristics of these products are availability in the commercial market such as the high number of suppliers available for component replacement, the accomplishment of the specifications of the most popular buses and standard interfaces and the quality level requirements which are accepted by industry.

The managers of high complex systems prefer adapt COTs solutions than other kind of solutions such as the proprietary products because of they are cheaper and present better performance. They present clear advantages such as the standard protocols adapted by the industry for Hardware and software components based on commercial solutions. The COTs product flexibility for design based on standard protocols and well stabilised HW and SW interfaces allow find solutions for real system engineer problems. It also allows establish system open architecture that is one of the more power obsolescence mitigation strategies in design. Some of the advantages for control or computing systems in Defence, Nuclear or Railway when they adapt open system architectures are listed:

- a. Facilitate the certification process of the products which allow accomplish the non-functional requirements such as the system availability, reliability or quality.
- b. The whole lifecycle cost such the procurement or development cost are reduced through the whole life cycle.
- c. The integration processes of components into subassemblies and assemblies and/or the integration of equipment into networks is less time consuming.
- d. Reduce the maintenance time and facilitates the technology insertions reducing potential risks.

Unfortunately the use of COTS product in complex systems presents some disadvantages:

- a. The complexity of large software applications make very difficult to run exhaustive testing activities.
- b. The commercial availability is becoming shorter due to the rapid technology changes in the market.
- c. The interdependence between hardware and software modules makes difficult to upgrade the software application which is running over a legacy hardware decreasing the system capability.
- d. The number of supplier to support application during long periods of time is reduced.
- e. It is difficult to manage the quantity of the spares in the inventory due to the rapid changes in the stock levels as the components become obsolete quickly.

5 SYSTEM AVAILABILITY MODELLING TECHNIQUES

The prediction of high availability systems mainly depends on the reliability, maintainability and supportability parameters as stochastic factors that influence the system's behaviour. The real systems such as ships, defence equipment and nuclear plants consists of hundreds and thousands of components interconnected, with different serial and parallel configurations, multiple state levels, different maintenance policies and failure and repair dependencies. Analytical methods such as Coloured Petri Nets or Renewal Markov chains (Cekyay and Ozekici, 2010) and simulation techniques such as Monte Carlo (Zion et al, 2005) or Discrete Event Simulation (Schryver, 2012) are the most appropriate set of methodologies to model the availability of these real and dependent systems. Some of the methodologies applied to predict the availability and reliability behaviour can be evaluated as follows:

- a. Simulation methods. This methodology is a time consuming technique but present the advantage of being an easy computing technique. This can be appropriate with the introduction of clear restrictions such as the description of the main reliability parameters with exponential distribution functions or the assumption of independence behaviour of the failure and repair times. The reliability theory describes the operational availability in terms of down time and uptime which are mainly represented by the mean time between failures MTBF the main time to repair MTTR and the mean logistic delay Times MLDT parameters

and is applied in the renewal alternating process (Yañez et al, 2005) or the design for availability approaches (Jazouli and Sandborn, 2012) which are both examples of the last availability modelling methodologies.

- b. Optimisation methodologies are based on heuristics and analytical methodologies. There is in the literature review four main techniques to find an optimal solution of the availability parameters at component level: “dynamic programming”, “integer programming”, “non integer programming” and “heuristic or metaheuristic algorithm implementation” which also require the introduction of some assumptions. The availability optimization problem of series- parallel configuration in repairable systems which represent a real problem description in the industry today can be modelled using the metaheuristic approach of genetic algorithms (Juang et al, 2008). It can give a solution near to the optimum saving computing time in comparison with Monte Carlo Simulation techniques.

6 COMMERCIAL TOOL APPLICATION REVIEW

The final objective of the management of long life systems is to implement a decision making processes based on risk assessment and predictive tools which imply the optimization of the obsolescence strategies to reduce the system impact in terms of cost, safety and performance. The industry today is aware of the lack of predictive tools to mitigate the impact of the obsolescence events in the performance based contracts (PBC). A general view of the commercial tools for the management of complex systems is listed:

- Operational Field: Failures Modes Effects Analysis (FMCA), Failures Modes Effects and Criticality Analysis (FMECA), Prognostic /Diagnostics techniques and modelling and simulation tools.
- Design Analysis: The High Reliability design tools, Design Failures Modes and Effect Analysis (DFMEA) and Computer Aided Design CAD tools.
- Logistic and Support areas: The logistic Support Analysis (LSA) tools, the Supply Chain Modelling Tools, the component Risk Assessment or the monitoring and forecasting tool.

7 DISCUSSION AND CONCLUSION

This research identifies the relevant aspects of the obsolescence issues and the main solution approaches to plan the management strategies of repairable and complex systems. The decision processes are described as a set of procedures focused on the development of optimal support, design and repair policies which mitigate the impact of the obsolescence events on high availability systems in the context of performance based contracts (PBC). This set of solutions can be supported and informed by a mix of tools aimed to quantify and estimate the behaviour of availability parameters based on stochastic simulation and an optimisation methodology and conducted to mitigate the support problems. The critical factors of the framework described are focused on the technology upgrades planning, the improvements of engineering processes in the testing, qualification and integration steps of subassemblies, assemblies and equipment, the identification and adaption of the appropriate obsolescence resolution approaches based on the companies capability , the inventory management and the long partnerships with the providers

The obsolescence management strategies review in performance based contracts presented in this research allow some open questions to further discussion:

1. How to measure the availability at system level in different sectors to estimate the impact of the obsolescence events on the operational availability and determine the optimal maintenance strategy?
2. What is the relevant set of design criteria, such as open architectures, to facilitate the logistics and support programs and mitigate the obsolescence problems?

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ANALYSIS OF THE “MAKE OR BUY” DECISION PROCESS IN A RESEARCH AND DEVELOPMENT SME

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ABSTRACT

Start-up SMEs face various challenges and difficulties during their existence and due to their nature they often lack knowledge and resources to fully address these challenges. Unlike large companies which have access to various resources, those resources are a significant gap for SMEs and the business owners have to rely on their own limited knowledge. The “Make or buy” decision is a critical decision in an organisation. This decision can affect current and future costs, capability and competences in the company and by taking best practice approaches and measures towards the decision making, extensive costs can be potentially saved. In this study, literature best practices have been reviewed. In addition a small company has been studied and the current practices of the company have been compared to academic best practices. The result of the study will be used to improve the “Make or buy” decision process in the company.

Keywords: SME, cost engineering, Make or buy

1 INTRODUCTION

Small and medium sized enterprises (SMEs) are an important part of a country’s economics and potentially contribute the most to a country’s economic growth. Hence helping SMEs will contribute to the recovery of the whole economy. Currently SMEs suffer from demand shock and shortage of credit. SMEs are more dependent on credit than large industries and they are mostly affected by direct and indirect linkage effects. Especially enterprises linked with other countries (Chowdhury 2011).

“Make or buy” decision is a crucial decision for an organisation and can have important effects on the future and existence of the organisation. In SMEs which have less access to extensive financial resources this decision is more critical. In addition, SMEs often lack the systems and knowledge for management and don’t have access to best practices. Knowledge in SMEs is mainly gained through experience and tactic leaning (Ates *et al.* 2013). In SMEs, management practices are directly related to manager’s personal skills and characteristics and because they usually hold several roles both operational and strategic, they don’t have necessary time resources and focus for managerial tasks (Fuller-Love 2006).

The research is done with the partnership of Samad power Ltd. Samad power is a SME, designing a micro cogeneration or Combined Heat and Power (CHP) system which is mainly intended to provide electricity and hot water for domestic users. The product is a technology breakthrough for small size CHPs. The Power output is intended to be at about 2 kW.

2 LITERATURE REVIEW

SMEs form 99.6% of UK's businesses and contribute to 49.5% of the economic added value and account for 54.3% of employment in the private non-financial sector. In addition "37% of SMEs are active in high-tech manufacturing and knowledge intensive service sectors which are considered key for the future competitiveness of the country" (European Union 15/10/2012).

European Union (15/10/2012) reports that the SME sector in the UK "is still struggling to cope with the crisis" and "of the key SME indicators, only the gross value added is now on a steady positive trend".

The first theoretical "Make or buy" decision making model was developed by Ronald Coase in 1937 and further development can be found in Oliver Williamson's (Williamson 1975) research in 1975. Coase (1937) introduced the "idea of transaction cost" in economics and developed the economic theory of the firm which was the basic model for "Make or buy" decision. Amenudzi (2009) in a structured review of "Make or buy" related research stated that "most of the decision making frameworks identified in the literature are not regarded as a standard tool or mechanic for making "Make or buy" decision, but had been used as an aid in decision making".

"Make or buy" is defined by Zenz (1994) as the decision of whether to make a product in-house or buy from suppliers. Probert (1997) defines "Make or buy" decision as whether to carry out a process or activity in your own business or to assign it to suppliers. "Make or buy" decision is not only limited to cost or to speed to the market of a product. Dale and Cunningham (1984) have mentioned other factors other than cost in the decision making and evaluated their importance. Suppliers' capabilities and quality are among the decision making elements. Also "Make or buy" decision making not only can be a cost saving decision, but is a strategic activity that can affect the future of company's activities (Fine 2000). Dale and Cunningham (1984) have concluded that "Make or buy" decisions can be "very complex, time consuming, interactive and affect many departments within a company".

Slack *et al.* (2007) mention that other than the short term effects of outsourcing, long term and strategic effects of outsourcing should be considered to.

Anderson and Anderson (2000) mention three "outsourcing traps":

1. A company loses its market dominance when its supplier acquires its proprietary technology and diffuses it to its competitors.
2. A company relies too heavily on a single supplier, which weakens its ability to negotiate favourable purchase agreements.
3. A company outsources a component or service to a vendor to reduce costs, only to encounter higher expenses or reduced functionality when putting the final product together"

Also Anderson and Anderson (2000) suggest 5 points to avoid outsourcing problems:

1. Long term considerations
2. Avoid outsourcing "core capabilities"
3. Partially outsource other critical capabilities
4. Use of more than one supplier
5. Strategic alliance development with suppliers

Due to the nature of SMEs and their vulnerability to environmental changes, many experts believe that SMEs should choose partnerships or strategic alliances in their business strategy to spread investment costs and possible risks and to be able to overcome resource and capability shortages (Li and Qian 2007).

3 RESEARCH METHODOLOGY

This study is part of a research topic of "developing a cost reduction and estimation methodology for start-up SMEs developing a novel green product". As a part of this research a case study is carried out in a start-up SME. The first step of the research was understanding the context and was done by

developing background knowledge in the research area and understanding challenges and characteristics of start-up SMEs.

In order to be able to have more in depth understanding of SMEs' activities and requirements, and to be able to affect the company's activities, action research was chosen as the research methodology.

In this type of research, with the location of the researcher in the researched company, closed observation of the SME activities would be used for data collection. Moreover in order to be able to implement the developed methodology, participation of the researcher in some activities of the SME was required. This includes involvement in different company meetings, office works and workshop activities.

The research involved dealing with quantitative as well as qualitative results. The data and findings were recorded by noting in a logbook. The research involved attending various company meetings including general review meetings and technical review meetings. Also it involved involvement in concept design and detailed design process and prototype testing. The minutes of the meetings were written for further analysis. Assisting different sections of the company such as technical, managerial and marketing sections helped to develop a general understanding of the organisation's performance.

The limited company size and the management and staff's optimism towards the researcher, created a preferred opportunity for wider data collection of different sections of the company.

The collected data was classified by dates and were analysed using different organisational mapping tools and data analysis methods. The company's function was modelled using IDEF0 diagrams in Microsoft Visio and the functions, inputs, outputs, mechanism and controls were entered using data collected from Samad. The current Make or buy method used in the company was mapped in the IDEF0 modelling.

Also as a part of the research a structured literature review was done by reviewing research outputs in the area of "Make or buy" and especially SMEs related research. A total number of 60 papers were review on the subject of SMEs relater "Make or buy" research.

4 CASE STUDY

A case study is being done on a company active in research and development of products. The company is a start-up small company based in Milton Keynes and consists of 12 employees. The company started up with the development of a domestic micro Combined Heat and Power (CHP) product called the Turbo Green Boiler (TGB) and developed its business by adding distribution of solar thermal units to its activities. Currently the engineering team has added engineering consultation and design to its activities. The company started with a team of 5 engineers and added other specialities including marketing and finance staff to its team.

The TGB development is at the stage of technology demonstration and the team is working towards a fully functional prototype. Most of the components of the product will be outsourced by Commercial off-the-Shelf (COTS) purchases. Some parts will be designed and built in-store and some will be manufactured externally and some parts may be both designed and manufactured externally.

The company has aimed to manufacture the TGB with lowest capital requirement in order to have competitive advantages against competitor products. To achieve this aim cost management methods have to be employed in order to achieve preferred cost results. Prior to selecting any method, an organisation has to be studied and current practices have to be identified and analysed. By identifying these practices, they can be analysed and compared to best practices in academia and current practices in other industries. The Case study was done with the aim to develop a method for "Make or buy" decision making in Start-up SMEs which is a part of a 'Cost reduction and value improvement framework for start-up SMEs'. The developed framework would be validated by running further case studies in the company.

5 RESULTS

According to European Commission's definition of SMEs and by considering number of employees, the studied company could be classified as a small enterprise, but by considering the turnover side of the definition, it could be considered a micro enterprise. In general the company is on the margin of transforming from a micro organisation to a small enterprise.

It can be observed that resource constraints is a day to day challenge for the company. The resource constraints exist in terms of human resources and financial resources. It can be expressed that lack of human resources is a consequence of financial shortages. Due to the criticality of cash flow in SMEs, selecting correct methods and processes are critical for future existence of the company. Make or buy decision can have long term effects on profitability of a business and wrong decisions can result in devastation of a business.

In the observed company it is seen that the decisions were made by the managers of the company which are also shareholders of the company. In making decisions, as they are shareholders as well, financial consequences of the decision are highly considered. But lack of Cost engineering knowledge is tangible in company's decision making and skilled staff in this area are needed.

For the process of “Make or buy” the company follows a “common sense” process and in developing this process, their engineering background has helped. As mentioned earlier the company lacks Cost Engineering experts, but the CEO has gone through an MBA course. Figure 1 illustrates an example of the “Make or buy” process in the studied organisation. This process was carried-out for a shaft and finally it was decided that the shaft be designed in-house and the fabrication outsourced.

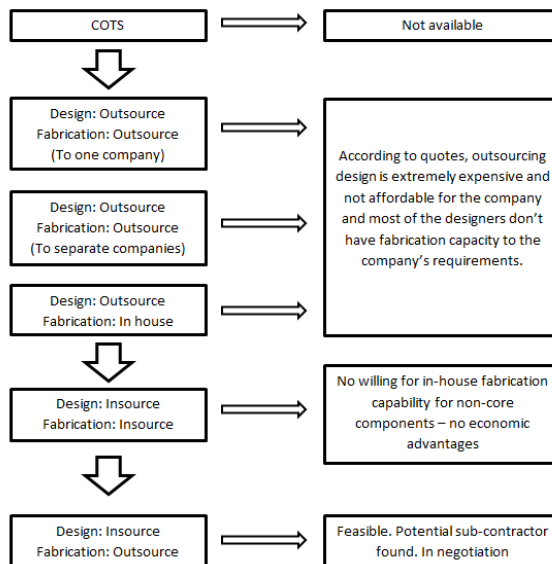


Figure 1: An illustration of people working in a factory.

The strategy of the company, so that be able to have a chance in the competitive market and introduce a low price product to the market was to use already existing products in the market. By combining them in a novel, logical and technical working order, a novel low cost product will be built.

In the process of decision making the priority option would be Commercial Off-The-Shelf (COTS). By having defined product specifications, similar parts and products which would satisfy the required specifications and have proven technology would be searched for.

Searching would be done by looking for vendors through the internet and contacting them through phone and email and also enquiring from experienced people in industry.

In the case of finding an appropriate product, a sample product would be ordered and different levels of testing would be performed to ensure the quality and suitability of the part.

One of the decision elements is the cost. As mentioned earlier, one of the main characteristics of the TGB would be low cost, and to ensure the low final cost of the product, low cost components have

to be used in the system. So the purchase price of the found products should be appropriate in relation to final product cost.

Also, during the process of purchase negotiations, the vendors supply capabilities and support capabilities would be considered too. The supplier should have the capability to supply products according to the company's production volume and manufacturing strategy. One of the other requirements from the supplier is the possibility of minor design changes to the components according to the company needs. This requirement could be overlooked for critical components where the weight of the other elements are higher.

Some available parts may be a component of an already existing product. The selection of COTS for these type of parts depends on the desire of the OEM to sell the part separate of the main product, otherwise other options have to be sought. For some products the price of the assembled product is less than the separate components of the same product.

If an appropriate part is not found, the next stage in the decision making process would be to consider designing the product. There would be several options in terms of insourcing or outsourcing this process. Table 1 illustrates 4 possible options for designing a new part to satisfy company's requirements in addition to COTS option. These four options are created by having two options of insourcing and outsourcing for both design and fabrication of parts.

Table 1: An illustration of people working in a factory.

		Design	
		Outsource	Insource
Fabrication	Outsource	X	X
	Insource	X	X

COTS +

By experience of requesting for quotation for outsourcing design and fabrication it is found that this option is not feasible and the company cannot afford costs of this option and selecting other options would be more cost beneficial. One of the reasons of ignoring this option is the unwillingness of the designers to hand over detailed design of the parts, very high cost of design from scratch and later modification constraints. Also until now no company was found to have production capabilities close to the studied company's volume requirements.

The company is not willing to invest in in-house manufacturing capabilities and as most mechanical parts are non-core parts, so the option of in-house manufacturing is not considered.

The option of outsourcing design and fabrication can have two sub-sections. As well as entrusting the design and manufacturing to one organisation, in order to gain economic advantages, the tasks can be given to separate organisations. Even there is the possibility of outsourcing the assembly to subcontractors.

It is understood that some parts of the TGB might have the potential to be considered as core competency such as the combustor. But the main competitive advantage in terms of design could be the way of assembly of the system and the controlling system which includes the control algorithm. It would be preferable to design and fabricate these parts in house. But due to in house production constraints and cost implications, external fabrication would have priority.

There are some obstacles for outsourcing for which one of the major obstacles is the confidentiality of core competence. In order to outsource any of the processes, a solution for this obstacle should be considered. In the studied company case the use of Non-disclosure agreements has been the common act. Also joint partnerships with suppliers in a way that both sides have financial incentives and non-financial interest in the project is another act used by the company.

6 CONCLUSION

During this study an SME company has been studied with the purpose of studying current practices in terms of "Make or buy" decision making. The research is done through action research, while the researcher is an observer and participant in the researched company.

During the study the lack of Cost engineering knowledge was seen in company actions and decision makings. The company had no access to Cost Engineering best practices and in the "Make or buy" decision making experience and common sense were the key players. While comparing to best practices, the negligence of some key elements can be seen in the company's decision making. It is seen that cost is the main element considered in the decision making process. It is important to transfer the best knowledge to the company in an effective way and make them aware of the importance of "Make or buy" decision in the future of their business.

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Optimisation of Production and Supply Chain Management

INVITED PAPER

**THE BEES ALGORITHM:
MODELLING NATURE TO SOLVE COMPLEX OPTIMISATION PROBLEMS**

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ABSTRACT

The Bees Algorithm models the foraging behaviour of honey bees in order to solve optimisation problems. The algorithm performs a kind of exploitative neighbourhood search combined with random explorative search. This paper describes the Bees Algorithm and presents two application examples: the training of neural networks to predict the energy efficiency of buildings, and the solution of the protein folding problem. The Bees Algorithm proved its effectiveness and speed, and obtained very competitive modelling accuracies compared with other state-of-the-art methods.

Keywords: intelligent optimisation, swarm intelligence, bees algorithm, honey bees.

1 INTRODUCTION

Many engineering problems entail tuning a number of system variables to optimise a given quality measure such as the reliability or accuracy of a process, or the quality or cost of a product. Unfortunately, the relationship between the system variables and the desired quality parameter is often complex, highly nonlinear, and ill-behaved. Implicit discontinuities and constraints on the state and input variables are also common.

Biological systems are known to be able to perform complex optimisation tasks, such as the natural adaptation of species, and group foraging and movement in social animals. Nature's near optimal problem-solving strategies often rely on stochastic approaches based on the interaction and self-organisation of large and decentralised ensembles of individuals.

Evolutionary Algorithms (EAs) (Rechenberg 1965), (Fogel, Owens and Walsh 1966), (Holland 1975) were the first optimisation methods inspired by the collective search process of a population of biological agents. Based on the Darwinian principle of survival of the fittest, EAs evolve a population of candidate solutions towards meeting some given quality measure(s).

Swarm Intelligence (SI) (Bonabeau, Dorigo and Theraulaz 1999) (Kennedy 2006) includes many recent model-free metaheuristics inspired by the collective intelligent behaviour of social animals. The SI paradigm is characterised by the use of a population of simple agents, some form of communication between the individuals, a decentralised control structure, self-organisation, and a random component in the agents' behaviour that fosters the exploration of new solutions. SI has found wide application in optimisation (Yang 2010), robotics (Gross and Dorigo 2009), image processing (Jevtic and Andina 2010), and computer graphics (Reynolds 1987).

One of the strengths of the above nature-inspired optimisation methods, is that they make no assumption on the properties of the fitness landscape. As such, they are applicable to any problem

amenable to being encoded via a fitness evaluation function, and allowing some sort of parametric representation of the solutions.

This paper presents the Bees Algorithm (Pham, Otri, et al. 2005, Pham and Castellani 2009), a nature-inspired intelligent optimisation method based on the foraging behaviour of honey bees. Two typical application cases are presented. In the first, the Bees Algorithm is used to optimise the weights of an artificial neural network (ANN) (Pham and Liu 1995) to predict the energy efficiency of a building. In the second, the Bees Algorithm is used to obtain the global energy minimum in a molecular cluster to find the configuration of a protein.

2 THE BEES ALGORITHM

In a bee colony, a small part of the population continually scouts the environment in search of new food sources (i.e. flower patches) (Tereshko and Loengarov 2005). When a scout finds a new flower patch, it rates the discovery according to its profitability (Seeley 1996). A bee that found a rich food source communicates the location of its discovery to idle nest mates through a ritual called the “waggle dance” (Seeley 1996). The length of the waggle dance depends on the scout rating of the food source, allowing more bees to be recruited to harvest the best rated sources. Some of the recruited foragers may also perform the waggle dance upon their return to the hive, mobilising further foragers to exploit the food source.

In the Bees Algorithm, a population of artificial bees is split into a small number of ‘scouts’ and a larger group of ‘foragers’. The scouts randomly sample the solution space, and evaluate the fitness of the visited locations (solutions). The foragers perform local search in the vicinity of known good solutions, looking for further fitness improvement. The amount of foragers allocated to a neighbourhood (flower patch) depends on the fitness of the solution, according to a mechanism mimicking the waggle dance of biological bees.

The algorithm is composed of several optimisation cycles, where new solutions are generated and compared with the best-so-far findings, and the highest ranking ones are selected for local search. If local search fails to bring improvements of fitness around a solution for a given number of cycles, the flower patch is considered exhausted (the local fitness peak has been attained) and is abandoned (Pham and Castellani 2009). The whole procedure is run until a satisfactory solution is found, or a given number of optimisation cycles are completed.

Without loss of generality, continuous optimisation tasks will be considered henceforth.

2.1 Representation Scheme

Given the space of feasible problem solutions $U = \{x \in \mathbb{R}^n; \max_i < x_i < \min_i \ i=1, \dots, n\}$, and a fitness function $f(x): U \rightarrow \mathbb{R}$, each candidate solution is expressed as an n -dimensional vector of decision variables $x = \{x_1, \dots, x_n\}$.

2.2 Initialisation Routine

The initial population is randomly distributed with uniform probability across the solution space. The population is fixed to ns scout bees. Each scout assesses the fitness of the visited site. The algorithm then enters the main loop. The sequence of evolution cycles is interrupted when the stopping criterion is met.

2.3 Waggle Dance Routine

The population is ranked, and the scout bees that visited the nb locations of highest fitness are selected. Each of these nb scouts recruit nest mates for local exploration of the flower patch it discovered. The number of recruited bees is allocated deterministically. The first ne elite (top-rated) sites amongst the best nb locations discovered by the scouts are allocated nre foragers, and the remaining $(nb-ne)$ sites are allocated $nrb \leq nre$ foragers.

2.4 Local Search Routine

For each of the nb selected flower patches, the following procedure is repeated. The recruited foragers (nre for the elite sites and nrb for the others) are sequentially placed with uniform probability in a neighbourhood of the high fitness location marked by the scout bee. This neighbourhood is defined as an n -dimensional hyper-box of sides $a_1, \dots, a_n$ centred on the position indicated by the scout. If one of the foragers lands in a position of higher fitness than the scout bee, that recruited bee is chosen as the new scout. At the end, only the fittest bee of each flower patch is retained. This bee becomes the dancer once back at the hive.

2.4.1 Neighbourhood Shrinking Subroutine

The size $a = \{a_1, \dots, a_n\}$ of the flower patches is initially set to a large value. For each variable a_i , it is set as follows:

$$\begin{aligned} a_i(t) &= ngh(t) * (\max_i - \min_i) \\ ngh(0) &= 1.0 \end{aligned} \quad (1)$$

where t denotes the t^{th} iteration of the Bees Algorithm main loop. The size of a patch is kept unchanged as long as the local search procedure yields higher points of fitness. If the local search fails to bring any improvement in fitness, the size a is decreased. The neighbourhood size is updated according to the following heuristic formula:

$$ngh(t+1) = 0.8 * ngh(t) \quad (2)$$

That is, the local search is initially defined over a large neighbourhood, and has a largely explorative character. As the optimisation process advances, the search is made increasingly detailed (exploitative) to refine the current local optimum.

2.4.2 Site Abandonment Subroutine

The neighbourhood shrinking procedure is applied each time the local search procedure fails to yield fitness improvement in a flower patch. After a pre-defined number ($stlim$) of consecutive stagnation cycles, the search procedure is assumed to have found the local fitness peak. In this case, the local search is ended and a new flower patch centred on a randomly generated solution is created. If the location being abandoned corresponds to the best-so-far fitness value, the location of the peak is recorded. If no better solution is found during the remaining of the search, the recorded best fitness site is taken as the final solution.

2.5 Global Search Routine

In the global search phase, $ns-nb$ bees are randomly scattered across the fitness landscape to evaluate new solutions.

2.6 Population Update Routine

At the end of an iteration, the new population of the bee colony is formed out of two groups. The first group comprises the nb bees associated with the centre (the best solution) of each flower patch, and represents the results of the local exploitative search. The second group is composed of the $ns-nb$

scout bees associated with a randomly generated solution, and represents the results of the global explorative search.

2.7 Stopping Criterion

The stopping criterion depends on the problem domain, and can be either the location of a solution of fitness above a pre-defined threshold, or the completion of a pre-defined number of evolution cycles.

3 APPLICATION EXAMPLES

The Bees Algorithm is used to solve two real-world optimisation tasks. The first task requires the optimisation (training) of the weights of two multi-layer perceptron (MLP) (Lippmann 1987) neural networks to predict the energy efficiency (heating load and cooling load) of buildings. The energy efficiency of a building is evaluated as a function of eight construction parameters, and the optimisation task entails the minimisation of the prediction error. The second task requires finding the minimal energy structure of a molecular cluster to find the configuration of a protein.

3.1 Energy efficiency prediction task

A data set of 768 samples of eight real-valued construction parameters (the independent variables) and two energy real-valued efficiency parameters (heating load and cooling load, the dependent variables) was created by A. Xifara and A. Tsanas at University of Oxford, UK, and is available through the UCI Machine Learning repository (<http://archive.ics.uci.edu/ml>).

The energy efficiency of a building is determined using one separate MLP to predict each of the two independent variables from the corresponding eight construction parameters. The two ANNs are trained to minimise the prediction error using the standard Backpropagation algorithm (Lippmann 1987) and the Bees Algorithm, and the results of 10 independent trials of the two procedures are compared. For each trial, the data set is randomly divided into a training set containing 80% (614) of the entries, and a test set containing the remaining (154) data samples. The structure of the MLPs is optimised by trial and error, and comprises eight input neurons (one per construction parameter), one layer of 10 hidden units, and one output variable (heating load or cooling load). The neurons of the hidden and output layers use respectively hyper-tangent and sigmoidal activation functions. The settings of the two training algorithms are detailed in Table 1.

Table 2 reports the median and percentiles of the root mean square (RMS) errors obtained in the 10 trials using BP and Bees Algorithm. For each output, the statistical significance of the difference of the results obtained by the two algorithms is tested using Mann-Whitney U tests (Table 2). In both cases the p-value is well above the standard significance threshold of 5% ($p < 0.05$), and the null hypothesis cannot be rejected. Using the nonlinear non-parametric Random Forests method, Xifara and Tsanas (2012) obtained a mean average error of 0.51 with a standard deviation of 0.11 on the heating load prediction task, and 1.42 ± 0.25 on the cooling load prediction task. Overall, it can be concluded that the Bees Algorithm obtains results that are comparable to those obtained by competing methods presented in the literature.

The evolution of the average RMS prediction error on the two dependent variables is shown in Figure 1, together with two sample plots of modelling results.

Table 1: Energy efficiency benchmark - BP rule and Bees Algorithm settings

BP Settings		Bees Algorithm Settings		Common settings	
Trials	10	Trials	10	Init. range for MLP weights	[-0.05, 0.05]
Learning cycles	100,0000	Evolution cycles (<i>lc</i>)	20,000	Training set	80%
Learning coefficient	0.1	Scout bees (<i>ns</i>)	8	Test set	20%
Momentum term	0.01	Elite sites (<i>ne</i>)	2		

		Best sites (<i>nb</i>)	8		
		Recruited elite (<i>nre</i>)	75		
		Recruited best (<i>nrb</i>)	25		
		Stagnation limit (<i>stim</i>)	5		

Table 2: Energy efficiency benchmark - Minimisation results

output	algorithm	10 th percentile	median	90 th percentile	M-W test
heating load	BP	0.46	0.52	0.57	p=0.1655
heating load	Bees Algorithm	0.47	0.55	0.65	
cooling load	BP	1.14	1.31	1.62	p=0.5787
cooling load	Bees Algorithm	1.26	1.33	1.64	

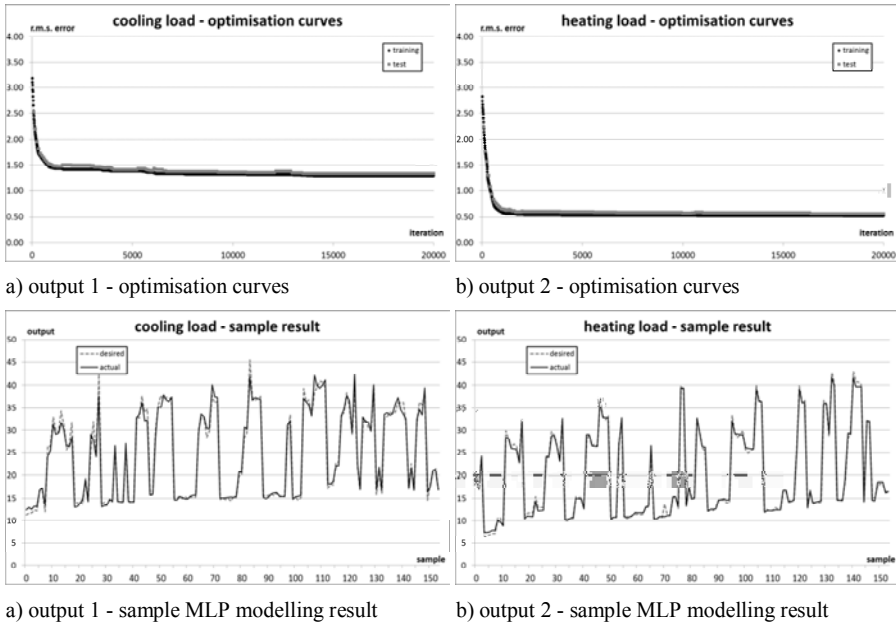


Figure 1: Optimisation curves and results of the Bees Algorithm

3.2 Protein folding benchmark

The protein folding problem consists of finding the minimal energy structure of a molecular cluster to determine the configuration of a protein (Vavasis, 1994). The energy function of the molecular structure is defined by the following non-linear partially separable function:

$$f(x_1, \dots, x_n) = \sum_{i=1}^{n-1} \sum_{j=i+1}^n r \left[\sqrt{\sum_{k=1}^3 (x_{ik} - x_{jk})^2} \right] \quad (3)$$

where $r(s)$ is the Lennard-Jones potential

$$r(\vec{s}) = s^{-12} - 2 \cdot s^{-6} \tag{4}$$

The vectors $\vec{x}_i = \{x_{i1}, x_{i2}, x_{i3}\}, i \in [1, n], i \in \mathbb{I}^+$ correspond to the positions of n atoms in the 3D space. The function f is non-convex, and has an exponential number of local minima (Mongeau, et al. 2000). The global minimum is easy to determine for $n \leq 4$, whilst it is unknown for $n > 4$ (Vavasis, 1994) (Mongeau, et al. 2000).

In this study, the four cases $n=3-6$ are considered. They will be henceforth called pf3, pf4, pf5, and pf6. The global minima for the four functions are given in Table 4, for $n>4$, they are taken from the optimisation results of Coleman et al. (1994).

The solutions are encoded using $3 \cdot n$ long strings of real numbers, which are built chaining the 3D vectors of Cartesian coordinates of atoms positions. The Bees Algorithm is employed to locate the minima of the functions. The algorithm is stopped when the known minimum has been approximated with a precision better than 0.001, or $cmax$ optimisation cycles have elapsed. The optimisation parameters of the Bees Algorithm are given in Table 3.

The results of 50 independent optimisation trials are given in Table 4. The table reports the number of successful trials (the solution found approximates the known minimum with a precision better than 0.001), the average error (difference between found solution and known minimum), the average number of iterations needed to find the known minimum, and the known minimum.

Table 4 shows that the Bees Algorithm is able to locate consistently and accurately the global minimum of the four protein folding minimisation problems. Figure 2 shows the fitness progress of the Bees Algorithm in the four minimisation tasks.

In general, the results obtained by the Bees Algorithm compare well with the literature. For a reference, the reader may compare the results plotted in figures 2a-d with those obtained by other six public domain optimisation methods reported by Mongeau et al. (2000).

4 CONCLUSIONS

This paper presented the Bees Algorithm, a recently developed nature-inspired parameter learning method. The effectiveness of the Bees Algorithm was demonstrated on two examples of real-world minimisation problems: the training of MLPs to predict the heating load and cooling load (energy efficiency) of buildings (minimisation of average prediction error), and the solution of the protein folding problem (minimisation of energy in molecular dynamics). The results obtained using the Bees Algorithm were comparable to those attained using state-of-the-art techniques, confirming the ability of the Bees Algorithm to solve complex optimisation tasks.

Table 3: Protein folding benchmark problem - Bees Algorithm settings

Function	Colony size	<i>cmax</i>	<i>stlim</i>	<i>ne</i>	<i>nre</i>	<i>nb</i>	<i>Nrb</i>
<i>pf3</i>	51	10000	10	2	20	4	5
<i>pf4</i>	51	10000	10	2	20	4	5
<i>pf5</i>	51	10000	10	2	20	4	5
<i>pf6</i>	102	5000	10	1	40	4	20

Table 4: Protein folding benchmark problem - minimisation results

Function	Bees Algorithm			Known minimum
	success	mean error	speed	
<i>pf3</i>	50	0.0000	1454	-3.0
<i>pf4</i>	49	0.0007	2346	-6.0
<i>pf5</i>	50	0.0000	3188	-9.1038
<i>pf6</i>	48	0.0008	148642	-12.712

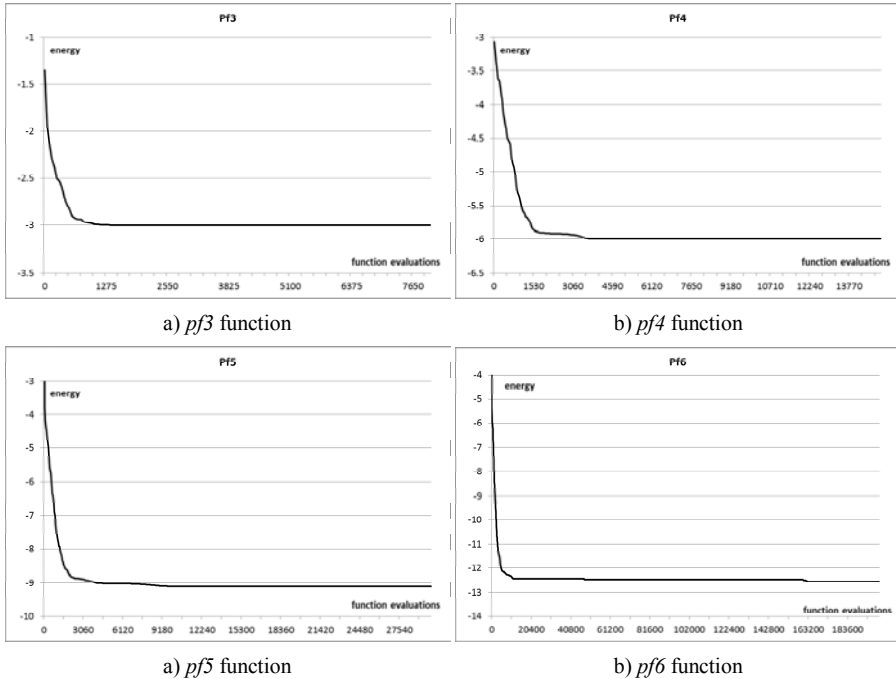


Figure 2: Optimisation curves of the Bees Algorithm

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PRODUCTION LOCALIZATION FACTORS: AN INDUSTRIAL AND LITERATURE BASED REVIEW

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ABSTRACT

Decision are commonly based on the available or easily accessible information; this is also true for more complex assessments like production localization. Where to locate production is often a key strategic decisions that has great impact on a company's profitability for a long time; insufficient business intelligence may therefore have grave consequences. Six production localization factor studies have been assessed to see if they are focusing on the same issues and if there are any gaps. A new approach for structuring localization factors and the localization process is then presented and assessed with regards to some previously identified critical issues.

Keywords: production system, production localization, industrial study, localization factors.

1 INTRODUCTION

European manufacturing companies have successfully operated on an international market for a long time. During the recent years the manufacturing industry has become even more global in its way of organizing manufacturing operations, both within their own manufacturing footprint and regarding suppliers and sub-suppliers. Functions are to a larger extent organized globally rather than based on region or country, and each function's localization is more and more based upon marked growth and customer demands rather than historical context. This is true not only for the larger corporations, also suppliers experience a stronger request from customers to join as new sites are established in new markets, or when the product portfolio is upgraded in current sites globally. Even though the debate on manufacturing outsourcing and off-shoring has become more balanced, the strategic process of determining the geographic site for a firm's production operations, i.e. production localization, is ever as important.

For years, researchers and practitioners have primarily detailed the aspects of production localization individually. Models and criteria have been tailored to specific problems, theories and decision objectives. Facilities location is a classic field of location theories, siting of one or more facilities in a way that optimizes certain objectives such as minimizing transportation costs, providing equitable service to customers, or minimizing delivery time (e.g. (Aikens 1985; Button 1993; Drezner 1995; Drezner and Hamacher 2001). Research on facilities localisation has been conducted from a multitude of perspectives since the pioneering work by (Ross 1896; Weber 1929; Hotelling 1929; Moses 1958), leading to an extensive knowledge base within the area. Research fields contributing to the area are models from operations research, public economics, operations strategy; these studies often focus on specific applications and cases. Still, the developed theoretical works on localisation tend to focus on a small number of decision factors (Pongpanich 1999).

Companies face this localisation challenge in different situations, such as enabling a growing production volume, entering a new market, introducing a new product or relocating a facility. The companies normally have at least one objective to consider in the location problem, in most cases to optimise cost and profit over time. However, during the recent decade a new set of aspects have gained momentum, influencing the strategy and design of the industrial network for tomorrow's successful industry. The localisation strategy has to function in a world of limited resources, change of values and a global economic view, and the decision of production location today relies on a more balanced set of decision variables than merely cost minimization.

The increasing complexity in decision variables call for a deeper understanding of the specific decision criteria behind production localisation decisions and production localisation strategy. The objective of this paper is to (1) review and structure a full set of decision factors in a production localization situation applicable for a larger global manufacturing company, and (2) discuss how the decision criteria can be included in the decision process to avoid insufficient or incorrect decision data.

2 METHOD AND MATERIAL

The literature base for the paper relies upon a broad search on literature on location decision criteria and processes applicable for production localisation applications. The empirical base for the paper relies on a long-term research project including five global larger manufacturing companies. Cases and established structures from the companies have been studied and related to a comprehensive set of literature in order to compile a full set of decision factors relevant for different production localization situations. The set of factors have in dialogue with the companies been structured in a functional/organizational hierarchical structure of decision factors. Based on the academic and industrial dialogues, the set of factors is included into a proposed decision process for production localization.

3 RESULT

3.1 Production localization categories in literature

To reach the right location decision, it is most important to select, analyse and evaluate the right location criteria (Yang and Lee 1997). From reviewing thirty-one central articles about location decision, it is clear that there is a huge number of location criteria having an influence on location decisions. Goetschalckx, Vidal, and Dogan (2002) classified location criteria from seven published strategic logistic models into four categories: *stochastic*, *taxation and cash flow*, *non-international* and *trade barriers*. Farahani, SteadieSeifi, and Asgari (2010) used a multi-criteria approach to approach localization problems and divided the criteria into six groups: *cost*, *environment risk*, *coverage*, *service level and effectiveness*, *profit*, and *other criteria*. Ferdows (1997) presented the drivers behind global spread of production and classified location factors into six categories: *government policies*, *market*, *skill and knowledge*, *risk*, *competition*, and *production and logistics cost*. Bergeron et al. (2005) classified factors in a site selection model into four groups: *geography and culture*, *environment*, *workforce*, and *cost and ROI*. Galan, Gonzalez-Benito, and Zuñiga-Vincente (2007) grouped location factors into five categories: *cost factors*, *market factors*, *infrastructure and technical factors*, *political and legal factors*, and *social and cultural factors*. Mentzer (2008) described seven key factors in effective facility location: *land*, *labour*, *capital*, *sources*, *production*, *markets*, and *logistics*.

Apart from the above six samples on classification, factors can be categorised into e.g. quantitative and qualitative categories. The quantitative is used for numerical values (for example cost, distance and revenue), while qualitative factors are difficult to measure in numbers such as policy, law and quality of work environment (Yang and Lee 1997); in addition, some of the qualitative factors are Boolean and only require a yes/no in an evaluation.

The above mentioned localization factor categories cover many of the key aspects in production localization. However, by mapping them in a 2x2 matrix, according to qualitative/ quantitative and if the categories address the development phase of the localization or the operational phase, it is apparent that the main focus lays on the easy to calculate factors associated with the production phase

(Figure 1). There are obvious risks associated with underplaying the impact from the qualitative factors and the costs during the development phase, e.g. (1) development of production facilities in new cultures and environments are complex project that often miss economical and time estimates; (2) the development itself may also have great impact on the ramp-up time and the final operations efficiency; (3) the quantitative factors during the operational phase often are beneficiary, while the qualitative ones often have a negative effect on the return on investment. In addition, many of the categories, specifically of the qualitative ones, have not been clearly identified as belonging to the development phase or the operational phase. There is an apparent risk that the location decision is based the operation stage, and that the calculations for the development are based on the direct costs for machines, utilities, and man-hours.

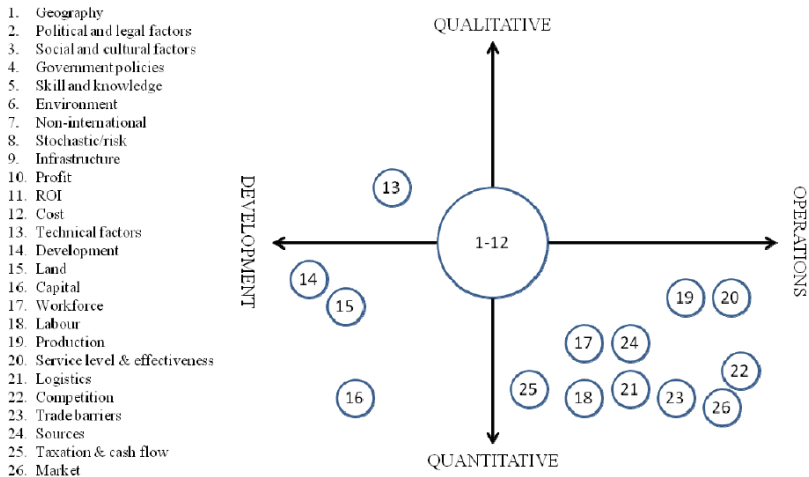


Figure 1: Localization categories in literature mapped according to development/organization and qualitative/quantitative

None of the categories discussed above specifically focus on the product; thereby, there is no clear connection between the product, the production processes and production system. By not highlighting the product, much of the complexity and many of the potential difficulties during both development and operation are hidden. A production location decision can be of different level of complexity, such as in scenarios 1-4 according to Figure 2 (analogous with Ansoff's classic growth matrix).

New product or technology	<p><i>Scenario 3</i> Where to locate production for a new product introduction?</p>	<p><i>Scenario 4</i> Where to locate production for a new product on a new market?</p>
Existing product	<p><i>Scenario 1</i> Where to locate production for a volume increase or relocation?</p>	<p><i>Scenario 2</i> Where to locate production for a marked expansion of current product?</p>
	Within current manufacturing footprint	Outside current manufacturing footprint

Figure 2: Four typical scenarios for production location decisions, increasing complexity (1 to 4).

A product's life cycle stages have been addressed as criteria to categorise factors that are in the early stage, companies often start producing products in the head quarter or research and development section. In contrast, at the end of product life, companies often locate the facility close to the market.

When assessing if a potential site is capable of meeting the production requirements, the company's previous experience is a key issue. An existing product or process is easier to start up a new plant for, and if a previous similar production localization has been done before, the requirements for local maturity is well known.

3.2 An holistic approach to production localization

Witnessed by the state of practice at the five companies in the study, and as previous authors also have emphasized, a location decision is a multistage decision with phases of strategic decisions as well as tactical decisions (e.g. Pongpanich (1999)). The companies do not have a full set of decision factors at hand initially, instead there are well established components supporting the localization process, such as investment calculation standards, relocation checklists, sourcing principles etc. However, the full localization process including decision factors is vague to both structure and content.

Concluding the literature review and company study, a set of decision factors is presented based upon eight corporate functions:

- Sales & Marketing
- Production System Installation & Ramp-up
- Production System Operation
- Sourcing & Purchasing
- Legal & Finance
- Facilities & IT
- Human Resources
- R&D incl. Product Development

It is concluded from the academic/company dialogues that a natural ownership and industrial decomposition is enabled by structuring the factors by corporate functions. This categorization empowers the functional owners and engages them in setting objectives, constraints and following up results during the localization process. Moreover, it enables both different perspectives to be naturally included in the decision process, and a singular issue, e.g. product complexity, can more easily be included in different decisions.

In accordance with the critique of cited studies on localization categories, greater focus has been put on separating development, installation and ramp-up of the production system, and the operation of the system. In addition, the product is highlighted, which more clearly shows the link between product complexity, production complexity, and localization complexity. For each of the categories, the factors have been mapped according to qualitative/ quantitative and development/operations (Figure 3)

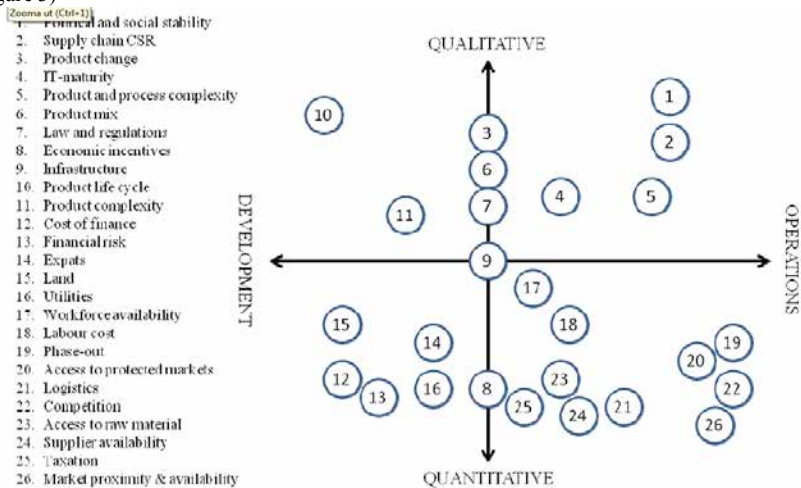


Figure 3: Holistic localization categories mapped according to development/organization and qualitative/quantitative

4 CONCLUSION

Location decision are commonly based on the available or easily accessible information. Business intelligence is often difficult to obtain or problematic to translate into economical terms; however, this is not an indication that qualitative and more complex factors do not affect the profitability of the localization. A decision to place a production plant at a certain location has long term effects on a company's profitability; insufficient business intelligence may therefore have grave consequences.

By comparing six categories of location parameter categories with the results from case studies at five multinational Swedish manufacturing companies, we have identified three important gaps in the literature: (1) qualitative factors are not addressed to a sufficient extent, especially not issues related to the product; (2) the development phase, including initiation and ramp-up, is not addressed to the same extent as the operational phase; and (3) location factors are addressed from only one perspective. These limitation do not allow for a more complex picture of the business intelligence to be developed.

We our cases we have found that location parameter categories should be based on company functions, and that the product and the development phase should be highlighted both for the categories and on the parameter level. Based on the studied industrial state of practice and existing body of research in production location factors, suggestions are made for future research within three areas: (1) process aligned models for production location decisions, (2) validated factor structures for production location decisions and (3) business case models for location decision.

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RISK ANALYSIS IN MANUFACTURING FOOTPRINT DECISIONS

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ABSTRACT

A key aspect in the manufacturing footprint analysis is the risk and sensitivity analysis of critical parameters. In order to contribute to efficient industrial methods and tools for making well-founded strategic decisions regarding manufacturing footprint this paper aims to describe the main risks that need to be considered while locating manufacturing activities, and what risk mitigation techniques and strategies that are proper in order to deal with these risks. It is also proposed how the risk analysis should be included in the manufacturing location decision process.

Keywords: risk analysis, manufacturing location decision process, manufacturing footprint.

1 INTRODUCTION

Companies' manufacturing activities are increasingly based on a global manufacturing footprint i.e. utilizing a manufacturing network design strategy, in order to increase competitiveness (Shorten *et al.* 2005). However, the manufacturing footprint is becoming increasingly complex with the large number of interdependent activities, as well as increasingly uncertain with unpredictable direction of changes. The uncertainty and complexity of the manufacturing localisation task challenges the possibility to develop suitable models to support manufacturing footprint decisions. A supportive decision model requires information that includes both strategic and economic implications of different geographical locations and considers a number of factors linked to the countries' different conditions, the position in the product life cycle and what the production system concept should look like (Bruch *et al.* 2011).

A key aspect in the manufacturing footprint analysis is the risk and sensitivity analysis of critical parameters. In order to avoid negative consequences when locating manufacturing, companies need to estimate different uncertainties concerning the site location selection (Miller 1992). The risks must therefore be analysed in the manufacturing location decision process. A risk could be defined as "*the uncertainty of financial loss, the variation between the actual and expected results or the probability that a loss has occurred or will occur*" (Broder 2006, p1). A distinction should however be made between an uncertainty that could be seen as unmeasurable while a risk is rather seen as a measurable uncertainty (Knight, 1921).

In order to contribute to efficient industrial methods and tools for making well-founded strategic decisions regarding the manufacturing footprint, this paper aims to describe the main risks that need to be considered while locating manufacturing and what risk mitigation techniques and strategies that are proper in order to deal with these risks. It also proposes how these risk mitigation techniques and

strategies could be included in the manufacturing location decision process. The scope of the paper is the manufacturing industry and a delimitation is made to large global manufacturing companies.

2 METHOD

The paper is based on empirical as well as theoretical findings. The empirical data was collected by a multiple case study with a holistic design (Yin 2009) where the risk analysis activities in two manufacturing location projects were studied also including the documentations and evaluations made after the project was carried out. The study was carried out during 2012 in two global manufacturing companies headquartered in Sweden. The companies are large industrial companies (>2000 employees) with a global customer base and R&D and production sites globally located. The data was collected by document studies and semi structured interviews (Yin 2009), see table 1.

Table 1: Data collection.

Case studies	Techniques	Details
Case A	Documents	Manufacturing location decision process
	Interviews	Senior project manager, Senior manager
Case B	Documents	Cost benefit analysis
	Interviews	Manager global production support

A review was made of literature and models for categories of risks to consider, as well as risk mitigation techniques and strategies relevant for manufacturing location decisions. The literature review included a broad range of literature such as production development and supply chain literature.

3 LITERATURE REVIEW

3.1 Main risks to consider in manufacturing location decision processes

The failure of a technical system can have roots in hardware, software, organization or the humans involved (Haimes 2009). Consequently a holistic approach of risks needs to be taken. The risks that need to be considered in manufacturing location decisions projects could be categorized differently. Dunning (1994) categorizes the risks of moving production into groups of economic uncertainty and currency exchange, coordination and environmental volatility, different business cultures and various political regimes. In addition, low technology capacity (e.g. Lan and Young 1996), political instability (e.g. Thomas and Worral 1994), natural disaster (Kusuda 1994), and competitive risks (Miller 1992) are categories of risks often mentioned. Supply chain risks is another category where an abundance of research is made (e.g. Tang and Tomli 2008, and Kaku and Kamrad 2011). Fredriksson et.al (2008) make a distinction between risks within the own supply chain and risks outside the own supply chain and specifies several manufacturing related risks that are not included in the above mentioned categories. The theoretically identified risks are here summarized and exemplified in table 2.

Table 2. Categories of risks to be considered in manufacturing location decisions projects.

Category	Example of risks
Manufacturing related risks - current site (e.g. Fredriksson, 2008)	Production loss. Unused area. Unused production equipment. Reduced work load for shop floor manager. Supervisors. Maintenance. Overhead costs that are distributed on less produced volume/ product entities. Amortisation costs for remaining unused production equipment. Support for the new site, i.e. resources which cannot be used at the current site.
Manufacturing related risks - new site (e.g. Fredriksson, 2008)	Long production ramp-up time. Long learning curve. Quality deficiencies before right level of quality is achieved. Extra costs for new production equipment. Up-dating and modification of documents. Disposal/ closing down costs. Level and accessibility.
Financial uncertainty (e.g. Dunning 1994)	Custom duties. Inflation. Interest rates/exchange controls and GDP/GNP growth. Income per capita. Infrastructure.
Social and	Language. Communication problems. Access to skilled workforce. Competence losses. Roles of

cultural differences (e.g. Fredriksson, 2008)	women and minorities. Religion. Average education. Ethics and moral. Reliability. Importance to do a good job. Importance to keep times. Residents: Age. Health. Distribution. General rate of wage change. High mobility. Urbanization.
Political instability (e.g. Thomas and Worral, 1994)	Stability of government. Ideology. Legal systems. Tax structure and tax incentives. Business climate. Country's debt. Regulations and restrictions that can affect operation.
Natural disasters (e.g. Kasuda, 1994)	Earthquakes. Rain periods. Hurricanes.
Competitive risks (e.g. Miller, 1992)	Quality of work. Lack of skill. Communication infrastructure. Robustness of public utility. Inadequate transportation.
Supply chain risks (e.g. Tang and Tomli, 2008)	Supply risks. Demand risk. Process risk. Intellectual property risks. Behavioural risks. Receivable risks. Inventory risks. IT system risks. Forecast risks. Procurement risks. Receivables risks. Inventory risks. Risks linked to competitor's actions and environmental legislations.

Prioritization of risks to handle is a central question. Risks less likely to occur and initially not deemed as a major economic risk, might at the end be more costly and dangerous than others. It might be more important to handle the risk which have significant consequences and low likelihood than to focus on risks with small consequences but high likelihood (Fredriksson *et al.* 2008). However, risks that are typically underestimated are e.g. communication problems at different levels based on absence of a common language, tacit knowledge which is not documented, out-dated documentation (e.g. product, production equipment routines), un-used capacity and supply base. It is therefore recommended to have routines that in a consistent way value potential business damages when e.g. considering commercial losses, loss of goodwill or un-used man- and machine capacity (Fredriksson *et al.* 2008).

3.2 Risk mitigation techniques

In order to handle risks and to deal with them in a holistic manner, risk mitigation techniques and strategies are required. In risk assessment normally three main questions are posed (Haimes 2009); *What can go wrong? What is the likelihood that it would go wrong? What are the consequences?* Techniques or strategies to deal with these questions are e.g. failure mode and effects analysis (FMEA), life cycle costing (LCC), multi objective analysis and analytic hierarchy process (AHP) (Haimes, 2009).

In an FMEA the most critical potential design and process failure modes are identified before they occur in order to eliminate their effect on early stages (e.g. Onodera 1997). The main elements that are identified are the seriousness or the effects of the failures (severity), the frequency of the failure (occurrence) and the ability to detect the failure (detection). When multiplying these factors, the risk priority number (RPN) is determined to pinpoint the critical failure modes associated with the process. FMEA guides in finding the optimum solution between alternatives by ranking the risks related to each alternative (Onodera 1997). The LCC method can be used for manufacturing location decisions by the identification of high cost areas and thus high risk areas (Woodward 1997). LCC is an economic evaluation tool that determines the sum of initial and future costs related to production operation; from the production location decision is made to the delivery of the product to the customer (Fabrycky and Blanchard 1991). Locating manufacturing in a foreign country often involves the investment of a large amount of money in the target country. Thus, FDI international statistics support the decision of which places have the most return on investment for foreign industries (Dunning, 1994). Another technique, Multi-objective decision trees, guide decision makers when handling several and often conflicting objectives of location alternatives (Haimes 2009). The decision tree approach uses a graphical representation and is efficient for analysing complex problems (Fulton 1971). AHP is a method for enabling the decision makers to structure a complex problem as a simple hierarchy. It evaluates a large number of often conflicting factors in a systematic manner.

What technique to use differ depending on the category of risk as well as the aim of the analysis. The techniques and strategies complement each other and could be considered in the manufacturing location decision process.

3.3 Risk analysis in the manufacturing location decision process

The identification of risks and the analysis of its consequences and likelihood to appear are essential to conduct in the manufacturing location decision process. In the production location field an abundance of literature concerning concepts and models for production location decision are suggested (e.g. Thanh *et al.* 2008; Fredriksson *et al.* 2008; Pongpanich, 1999), and summarized (e.g. ReVelle *et al.* 2008). Risk assessment is considered to different extension in these models. In a manufacturing location decision model proposed by Pongpanish (1999) the phases of investigation, identification, evaluation and selection are described where the risk analysis is mainly focused in the last phase where the location is selected. In a conceptual model of the process for efficient manufacturing location decisions proposed and presented in Bruch *et al.* (2011), a risk and sensitivity analysis is proposed to be made in the final part of the process. This analysis aims at identifying critical factors concerning risk, uncertainty and impact for each alternative, also considering the phases of investment, ramp-up, operations and phase-out. The outcome of this analysis supports the development of the business case, which should be the basic decision data for the decision making process. Despite the large amount of models suggested and the fact that the field of location theory and modeling is an area that traces its roots back to the first half of the 20th (ReVelle *et al.* 2008) the support used in industry often is insufficient. In addition, it is still not clear how and when risk assessment should be considered in a consistent way during the manufacturing location decision process.

4 EMPIRICAL FINDINGS

In order to study how risk assessment could be made in the manufacturing location decision process two case studies were conducted. It was studied how the risk assessment was performed in two manufacturing location projects at two different companies as well as what documented support that was used.

4.1 Case A

The manufacturing location project in Company A was initiated due to a need to expand the company's market, decrease the loss of market share and locating close to market and key customers.

When the project was carried out the company did not have a documented support for manufacturing location decisions. The knowledge was collected based on the gained experience from a number of previous projects. By the analysis of the interviews and document studies a location decision process emerged including the phases: identification of drivers for relocation, strategic decision, consequence analysis, and final decision. In the first two phases, potential risks were not identified or analysed. However, the consequence analysis included a risk evaluation. The risk factors identified in the process were related to:

- *Manufacturing related risks:* Delay on equipment release, Investment limitations, Keeping the employees motivated on the current manufacturing site, Ensure continuous flow of products, Higher demands on profitability (KPI), New work organisation on the new manufacturing site particularly on the maintenance side.
- *Social and cultural differences:* Collaboration between different sites, Language and cultural barriers, Transfer of knowledge from the current to the new manufacturing site, Available time and resources, Skills of the people involved in the project management, Preparation of documents.
- *Product development:* Under-estimation of the time and effort needed to get the approval of the customer for the modifications in the product design, Introducing new products and achieving reliable forecasts.

After the project was carried out a documented process was developed to even better support manufacturing location decision projects in the future. In this support a holistic approach was taken involving identification of risk level concerning knowledge transfer, organization, cultural aspects, sales, product development, production development and operations, local rules and regulations and security. In the developed process the phases idea, feasibility study, pre-study, realization and closure were included. Risks were treated in all phases except the final closure phase. In the idea phase the

idea was verified and a risk assessment concerning e.g. knowledge transfer was performed. In the feasibility study phase the risk level with the project was identified on a general level. A scenario-based risk and value evaluation was performed in the pre-study phase. Finally, in the realization phase, the main activities concerning risk handling were performed. In this document no additional instructions of how to handle the risk assessment were given. The company argued that every project is different from each other and the intention with their documentation was to avoid upcoming potential risk rather than being a complete list or exactly state how to make the risk value.

4.2 Case B

The aim with the manufacturing location project in Case B was to reach a new market. The company intended to start produce their mature products in the BRIC countries and therefore this project was initiated. When the case study was carried out the localization was still not carried out.

The company in case B had no documented support for manufacturing location decisions. The decision was based on strategic reasoning with a focus on cost but not based on the risks involved. The cost calculations were made based on several assumptions. No risk analysis was made before the location decision was taken. According to the manager for global production support, a risk assessment should have been done much earlier, before the decision was taken, and also during the location decision process. Problems identified in a later stage, after the decision was made, was mainly linked to the supplier interaction. The company had a difficulty to find suppliers that could offer a good price with a high quality. The knowledge transfer to suppliers was another difficulty since there was a risk to spread sensitive information concerning the products. In order to better support manufacturing location decision projects the company had started to develop a support model of a stage/gate character, complementing existing processes.

5 RESULT AND CONCLUSION

In literature there are several risk mitigation techniques presented to handle risks and to deal with them in a holistic manner. There are also an abundance of models concerning concepts and models for production location decision. However, it is still not clear how to carefully consider risks within these models. This paper describes main risks that need to be considered while locating production activities and introduce risk mitigation techniques to deal with these risks. In order to contribute to efficient industrial methods and tool for making well-founded strategic decisions regarding the manufacturing footprint risks must be identified and assessed in the manufacturing location decision process. The empirical findings illustrate that a support for this is needed and that it preferable is of a stage/gate character since this is a format often used in industry. Figure 1 illustrates how to involve risk analysis in a manufacturing location decision process, based on the process described by Pongpanich (1999), Bruch *et al.* (2011), and in case study A as well as the risk mitigation techniques and the risks categories based on the literature review and case study A.

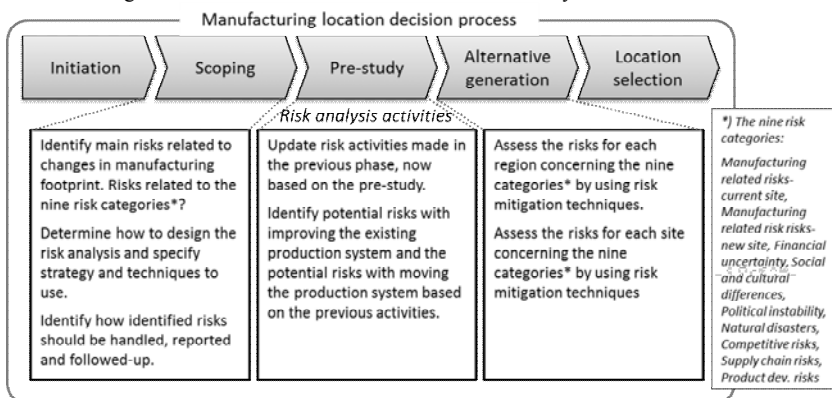


Figure 1: Risk assessment in manufacturing location decision process

The result of the paper give input to future research aiming to develop a supportive decision model of manufacturing localization. A process for including risk assessment activities is suggested involving both identifying potential risks as well as techniques needed to deal with the risks.

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A MODIFIED AHP ALGORITHM FOR NETWORK SELECTION

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ABSTRACT

This paper addresses the concept of ranking networks to the multiple criteria of customers to find the best and alternative networks. The use of modified AHP algorithm has been shown to provide better network ranking for reasonable customer objectives than the traditional AHP method. Both the traditional method and the proposed method produced results subjective to the customer requirements. However, the proposed method is more intuitive to the customers through direct capture of their exact requirements rather than an interpretation of their requirements through pair-wise comparison alone. Also, the proposed method is less time-consuming and results are of higher quality.

Keywords: AHP, Manufacturer networks, Multiple Criteria Decision Making.

1 INTRODUCTION

The manufacturing network should provide alternatives to the current network when it is being affected by unforeseen problems which stem from today's uncertain and turbulent markets and some environmental factors (Christopher et al. 2004). However, in the midst of the problems that a manufacturing network may face, the customer requirements must still be met as far as possible. Therefore, the ranking of alternative networks by the analysis of the multiple criteria request by customers should be provided. This method is referred to as Analytical hierarchy process (AHP) (Saaty 1990).

There are several methods to solve ranking problems. The weighted sum model (WSM) method is probably the most commonly used approach (Fishburn 1967). However, the model does not perform well on multi-dimensional problems. The weighted product model (WPM) method can be applied in ranking of networks but the result of AHP would be more credible. Since there is no dependency between the decision criteria and the alternatives, analytical network process (ANP) method is not necessary for the scope of the project (Saaty et al. 2006). The AHP method appears to be the best method for the scope presented. The method has been applied in several areas of manufacturing and has been shown to yield better results for the selection of machine centres based on individual usage performance of the components of the machine rather than other decision making methods (Ic et al. 2012). The AHP method has also been found in hybrid methods for the selection of best suppliers in small scale manufacturing organizations (Singh Verma and Pateriya 2013). Fuzzy Analytical Hierarchy Process has been used to determine the most important supply chain risks and the corresponding risk management strategies for an iron and steel manufacturer (Sofyalioğlu and Kartal 2012). Another application example of the method is the strategic planning in manufacturing firms by evaluating the importance of the SWOT factors affecting the firms and the marketplace (Görener et al. 2012).

AHP method relies on a well-defined mathematical structure of consistent matrices and their associated eigenvector to generate weights for every criterion of decision (Forman 2001). There are some limitations when using the AHP approach. Firstly, when the number of matrices become large, the consistency will become very poor (Saaty 1977). To reduce the biases caused by subjective judgment, modified Fuzzy AHP with kernel density estimation was proposed (Li et al. 2012). Secondly, the completion of $n(n-1)/2$ comparison, where n is the number of tasks, can become an onerous task if n become larger (Harker 1987). However, for the purpose of the paper, one well-defined matrix was used.

In this paper, a modified AHP algorithm which can be used in the networks ranking is presented. The comparison between traditional AHP method and modified AHP method is made. Finally, the benefit and limitation of modified AHP algorithms is mentioned.

2 METHODOLOGY

For the network ranking model to work, for each job of the manufacturing networks, the cost, lead time and quality performance must be available. The goals of the jobs are set as the variables namely maximum cost, maximum time, maximum quality, expectation cost, expectation time, expectation quality as well as a ranking scale. These information are used by the traditional and proposed AHP algorithms to calculate the rank of the networks. In section 2.1, the variables are described. Section 2.2 presents the AHP algorithm and section 2.3 describes the modified AHP algorithm.

2.1 Definition of input variables

When a set of jobs was issued, the simulation software allocated the jobs to the manufacturers on first come first served basis. This allowed the cost, lead time and quality of each job to be initially determined. At this point, the customer objectives for the job was inputted in terms of maximum cost, quality, lead time and expectation cost, quality and lead time. The maximum values were what the customer was ready to accept for that job. The expectation values were what was thought to the competitive values expected by the customer for that job. The customers would set these values based on their requirements. The criterion tolerance is defined as the difference between the maximum criterion value and the respective expectation value. The AHP scale denotes the maximum value a pair-wise comparison can received in the AHP matrix. The traditional scale is a one to nine scale. In later sections, the influence of AHP scale on the results is presented.

2.2 AHP Algorithm

The AHP algorithm involves constructing a matrix expressing the relative values of a set of attributes. The judgments are assigned a number on a scale. Table 1 shows the conventional scale.

Table 1: Scale of Relative Importance (Saaty 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	when compromise is needed

Considering a set of n objects to be compared $C = \{C_1, C_2, \dots, C_n\}$ and the relative importance weight of C_i to C_j is denoted by a_{ij} to form a square matrix A for a job where $a_{ij} = \frac{1}{a_{ji}}$. Therefore, a_{ij} is either a number in Table 1 or its reciprocal number.

The weights are consistent if they are transitive, that is $a_{ik} = a_{ij}a_{jk}$ where i, j and $k = 0, 1, 2, \dots, n$ and k is the index of unique pair of objects. Then the eigenvector ω and the eigenvalue λ is calculated for which $A\omega = \lambda\omega$. This is called the eigenvector analysis. If matrix A is a consistent matrix, $\lambda = n$. The probability of getting a consistent matrix based on human judgment is low and therefore, the ω vector satisfies the following equation instead: $A\omega = \lambda_{max}\omega$ and $\lambda_{max} \geq n$.

A Consistency Index is calculated and needs to be evaluated against judgments made completely at random. The Consistency Index is given by $(\lambda_{max} - n)/(n - 1)$. Then a true consistency ratio is calculated by dividing the consistency index for the set of judgments by the index corresponding to the random matrix. The consistency index is accepted when consistency ratio is smaller than 0.1.

The final weight of each network is the sum of the vector of a network in every criteria times the vector of that criteria.

$$\text{Final weight} = \sum_{n,c} [w_n] * [w_c] \quad (1)$$

The traditional AHP algorithm is appropriate for analysing a small number of objects however when the number of comparison increases, the error by human judgment and therefore the decrease in matrix consistency become significant. The next section addresses the issue with a proposed modifications to the AHP algorithm.

2.3 Modified AHP Algorithms

The number of manufacturing networks can become a large number and the pair-wise comparison of objects based on human judgment can become unreliable. A large number of comparison will increase the consistency ratio above 0.1 which means that the resultant weights cannot be used. Therefore a different method is proposed. The criteria of cost, time and quality are all quantifiable. Traditional AHP method acquire the pair-wise comparison values for the criteria by human judgment. In the modified AHP method, the formula below would be used.

$$p_k = \frac{P_k}{t_1} \quad \text{where } P_k \text{ is the cost of network } k \quad (2)$$

$$r_{k,j} = \frac{P_j}{P_k} \quad \text{where } r_{k,j} \text{ is pair-wise number in reciprocal matrix} \quad (3)$$

$$t_1 = p_{max} - p_{exp} \quad \text{where } t_1 \text{ is price tolerance, } p_{max} \text{ and } p_{exp} \text{ is max and expectation price} \quad (4)$$

$$t_2 = l_{max} - l_{exp} \quad \text{where } t_2 \text{ is time tolerance, } l_{max} \text{ and } l_{exp} \text{ is max and expectation time} \quad (5)$$

$$m_{0,1} = \frac{p_{max} t_2}{l_{max} t_1} \quad \text{where } m_{0,1} \text{ is the relation between price and lead time} \quad (6)$$

Similar equations can be used for the criteria of time and quality. The reciprocal matrix will remain consistency in the whole procedure as it is not subject to the bias of human judgment.

The modified AHP algorithm is performed in five steps using an in-house simulation software:

1. Create manufacturing scenario with jobs and manufacturers

2. Generate the cost, time and quality offered by each manufacturing network for every job on a first come first served basis
3. Remove the networks that offer values larger than the maximum lead time, cost and quality
4. Utilize the AHP algorithms to calculate the weight of every remnant network
5. Rank the networks by total weighted score

3 RESULTS AND DISCUSSION

The results obtained in this study can be divided into two sections. The first section shows how the proposed modified AHP algorithm performs when the scale is 0...9, 0...1000 and when the scale uses discrete and continuous numbers. Also presented is the change of the weight of the criteria when the maximum and expectation values are changed.

3.1 Relationship between weight and customer objectives

The parameters used to define the customer objectives for a job is as follows: (i) maximum price = 24000, (ii) maximum time = 6, (iii) maximum quality = 16, (v) expectation time = 5, (vi) expectation quality = 12. Table 2 shows the possible manufacturing networks for the job.

Table 2: Possible networks for a job

Networks	Price (£)	Quality (dppm)	Lead Time (h)
1	7879	13	4.92
2	23352	10	
3	41717	13	
4	35803	8	
5	8762	15	
6	49513	8	
7	13224	10	
8	34099	11	
9	20584	10	
10	42134	13	

When the expectation price was set to 10600 and when a discrete scale was used, the network ranking yielded completely different rank than when the AHP algorithm used the continuous scale. The network rank result provided by discrete one was {7, 9, 2, 1, 5} comparing with the result {1, 7, 5, 9, 2} created by the continuous scale. The continuous scale created a smoother profile and relative to the objectives of the customer, a much better ranking of manufacturing networks was generated. When using a discrete scale of 9 or 1000, the turbulence was generated because of the error of utilizing integer to replace decimals. However, the modified AHP algorithms can naturally generate a perfect curve when a continuous scale is used. Furthermore, the AHP with discrete scale cannot detect slight differences in the network offerings. Although network 1 had better cost, quality than network 5, the discrete type could not identify that network 1 was better. On the contrary, the modified AHP algorithm which is more sensitive can discern which network is better even when the difference is inconspicuous. Figure 1 shows the change in the importance of the price when the expectation price changes.

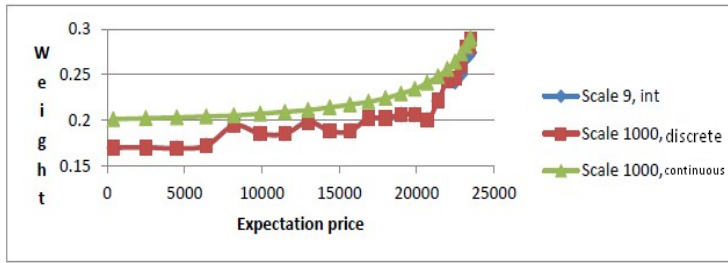


Figure 1: Comparison of price weights based on different scales

Next, a sensitivity analysis was carried out to show how the criteria weights changed when the objectives of the customer changed. Given that the difference between the expectation price and the maximum acceptable price for the job is high, the weight on the price is low as the algorithm assumes that the customer is willing to accept a good range of prices. This is defined in this paper as the criterion tolerance. As the expectation price approaches the maximum acceptable price, the price criteria increases in importance and consequently the associated weight increases. It is important to notice how the weights of the lead time and quality changes accordingly because the weights must sum up to 1. Figure 2 shows the profile of the weights of every criterion when expectation price is changed.

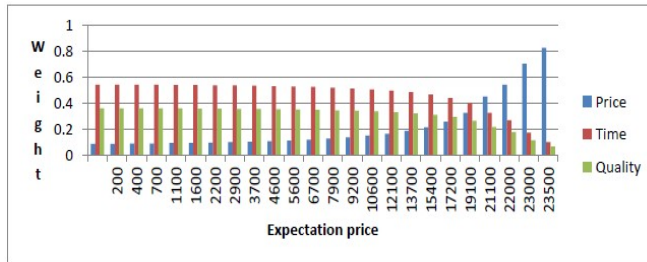


Figure 2: Criterion weight based on different expectation prices

Given that the maximum acceptable price for a job is changed and the expectation price is fixed at 12, 000, the price tolerance decreases as maximum price decreases. Therefore, the algorithm assigns a higher weight for price and consequently lower weights for lead time and quality. Small criterion tolerance indicates the customers are much more concerned in that criterion. Figure 3 shows the criteria weights when maximum price is changed.

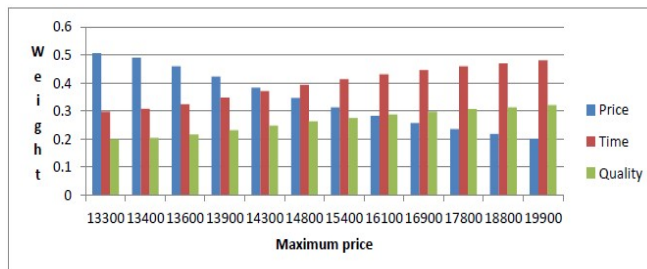


Figure 3: Criterion weight based on different maximum prices

3.2 Qualitative comparison between traditional AHP and modified AHP

There are several problems associated with using traditional AHP method in networks ranking. AHP scale from one to nine is evaluated by human nastic movement which may differ for different people. Nastic movement is the degree of response to stimulus, in this case the stimulus is the comparison of two criteria. Therefore, consistency ratio should be calculated to ensure reliability of the results. The traditional AHP method cannot avoid the error caused by the nastic movement when the number of objects increase. Modified AHP method guarantees the consistency by mathematical method and is more reasonable and tractable. Therefore, the consistency ratio need not be calculated because the formula, previously mentioned in section 2, guarantees the weights are consistency.

4 CONCLUSION

In this paper the modified AHP algorithm has been used to provide better network ranking. It has been demonstrated that the selection of networks based on multiple criteria using modified AHP has been successful. Once the number of network grows, the uses of modified AHP algorithm can prove to be an effective and reasonable method to rank manufacturing networks. This project demonstrated the benefits of using modified AHP in network ranking based on quantifiable criteria and made a comparison with traditional AHP. The results of this project improve traditional method in networks ranking.

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**ON THE PROFILE INTENSIVE BIW DESIGN AND OPTIMIZATION
-THE FRONT MODULE CASE STUDY-**

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ABSTRACT

The European automotive industry is known world-wide as the technically most advanced and innovative. Based on the competitiveness of global market, it is an emerging challenge and puts forward the need of flexibility for automobile OEMs and the product's ability to meet the demands of the continuously changing customer's behaviour. Therefore flexible processes have to be implemented during the design process of a BiW in order to achieve a flexible and modular product. In this paper profile intensive design of a front module has been developed under the prism of lightweight design. Profile intensive design offers to the manufacturer higher levels of flexibility and ability to adapt to the market needs efficiently and more quickly. Evaluation of the proposed design has been made through Design of Experiments. Finally Response Surface Method has been used for predicting the response of the front module when design variables are being changed.

Keywords: body in white, optimization, lightweight.

1 INTRODUCTION

The economical use of energy and other limited resources and the protection of the environment will be one of the main influencing cornerstones of tomorrow's mobility. Intensive efforts in the automotive industry focus on further reduction of CO₂ emissions and higher energy efficiency in all phases of vehicle life cycles. EU have set the target in 130gCO₂/km for a class A car until 2014 and 95gCO₂/km until 2020 (EU Press Release. 2012). Reduction of fuel consumption and CO₂ emissions can be achieved primarily by power train or vehicle technology related measures. Consequently, development of lightweight design plays a major role for further fuel consumption reduction.

Moreover third markets are growing fast, changing the trade flows. As a result OEMs have to further increase their flexibility in order to meet customers' needs. It is clear more than ever that a lot of challenges are emerging towards automotive industry which will lead to change of vehicle design. Integral design which is the main trend cannot follow the diverse consumers' environment. Previous design optimization approach cannot be adopted in order to achieve further weight reduction and in extent reduce vehicle emissions. Lightweight design philosophy has to be implemented and not only

in terms of conceptual design of a vehicle but also in manufacturing and material design of an automobile.

As a result modular and lightweight design can be used to confront the future challenges. A modular architecture presents a one-to-one correspondence between modules and functions and specifies de-coupled interfaces between components (Pandremenos et al. 2009). This way, a high degree of customization can be achieved, satisfying different needs (Chryssolouris et al. 2008). On the other hand weight reduction can help the automotive industry to meet the environmental target. Powertrain developments can help a lot in this direction with more efficient engines but Body in White (BiW) possesses 30% of the vehicle weight (Zhang et al. 2007). Weight reduction of 100kg reduces fuel consumption about 0.3-0.4l/100km.

However, modular and lightweight design will bring changes to the whole production line as new materials may be used to reduce weight (lightweight material design) and consequently new joining technologies have to be developed (Nunez 2009). Moreover modularity may affect the production line in terms of that rescheduling may be needed or even definition of new modules and as a result new sub-assembly lines.

In this paper, a profile intensive BiW design of the front module is presented. Front side rail, rear side rail and shotgun have been re-designed to be manufactured from a progressive and simple roll forming process, processes which can lead to a high degree of flexibility. The study focuses on front module but it can be extended to the rest of the modules. Moreover, Design of Experiments (DoE) has been coupled with Response Surface Method (RSM) in order to reduce weight and to improve torsional stiffness.

2 DESIGN PROCESS

A profile intensive BiW design methodology is being proposed. For evaluation of this methodology, the front module of Fiat Stilo has been selected. Front module is one of the most important modules that should be taken in account during lightweight design because on it, the engine is installed, which has a fixed weight and it is not a design variable during BiW design. The majority of the automotive parts are produced from deep-drawing or casting processes. However these processes do not guarantee flexibility of design because for a simple change, modification of tooling is required, thus most of the times lead to a product that cannot meet the customer's needs. However, processes such as roll forming and extrusion can deliver parts which lead to a scalable product. In order to substitute and simultaneously respect the design philosophy of Fiat Stilo BiW, a design 'template' has been developed. This design template, Figure 3, gathers all the design characteristics such as dimensions, joining interface planes etc. As a result, the changes will be occurred in BiW's design will not cause any design interference.

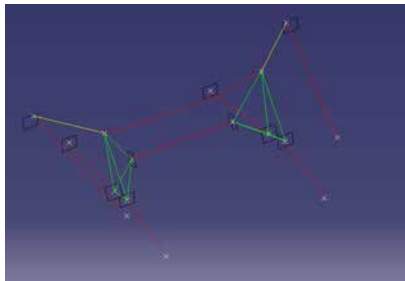


Figure 1: Design Template

The proposed design includes re-design of some parts in respect of the roll forming and flexible roll forming processes. The final target is to reduce the weight of the front module, and increase torsional stiffness. ANSYS Workbench has been used for setting benchmark values in order evaluate the profile design. The two characteristics which have been measured are torsional stiffness and front module's weight. Torsional stiffness has been measured as it is described in (Tebby et al. 2010). For the measurement of front module mass, CATIA V5R18 Measure module has been used and a constant thickness of 1.2mm of steel has been selected as material.

Table 1: Fiat Stilo Benchmark Values

Weight (only Front Module measured)	42.18 kg
Torsional Stiffness	14833 Nm/deg

Under these assumptions, front side rail (fsr), rear side rail (rsr) and shotgun have been re-designed in order to be manufactured from cold roll forming process (fsr and rsr) and flexible roll forming (shotgun). Cold roll forming processes has been selected due to the cost advantages towards hot stamping which is on average 40-60 % cheaper. The reason for this is the fast production cycle for each cold formed part. The U profile has been selected for the parts. As a result, numerous joining points on the flanges can be provided for the connection of the front with the floor module. Moreover, flanges in the front side rail provide freedom to the selection of engine mounting points. After the design completion, an evaluation has been conducted and the results can be seen in Table 2.

Table 2: Comparison of Stilo and Profile Front Module

	Fiat Stilo Front Module	Profile Front Module	Difference
Weight (only Front Module measured)	42.18 kg	36.62 kg	-13.18%
Torsional Stiffness	14833 Nm/deg	15248 Nm/deg	+2.7%

3 DESIGN OF EXPERIMENTS

Conducting a set of experiments using orthogonal arrays allows the effects of several parameters to be determined efficiently (Phadke 1989) in relevance to a defined response. In the current work, the L_9 orthogonal array has been used. The statistically designed experiments are simulation runs, changing each time specific design variables, implemented using FE calculations. The variables and the ranges are shown in Figure 5 and Table 3 respectively.

Table 3: L_9 Virtual Experiments

Expt. No.	A. Shotgun Profile Height	B. Reinforcement Angle	C. Front Side Inclination	D. Cowl Member Inner Distance
1	Level 1	Level 1	Level 1	Level 1
2	Level 1	Level 2	Level 2	Level 2
3	Level 1	Level 3	Level 3	Level 3
4	Level 2	Level 1	Level 2	Level 3
5	Level 2	Level 2	Level 3	Level 1
6	Level 2	Level 3	Level 1	Level 2
7	Level 3	Level 1	Level 3	Level 2
8	Level 3	Level 2	Level 1	Level 3
9	Level 3	Level 3	Level 2	Level 1

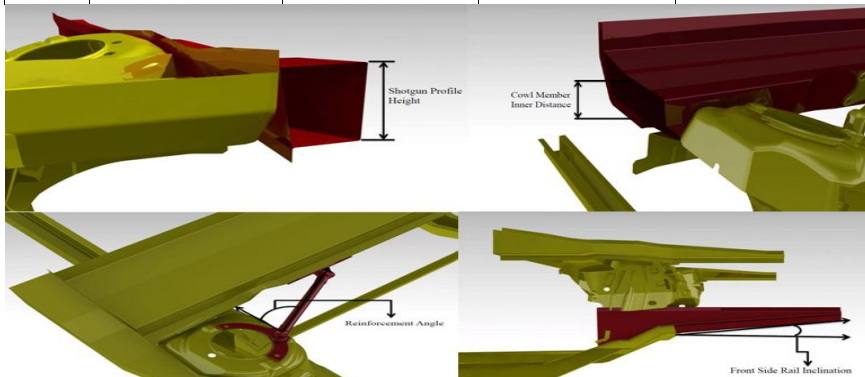


Figure 2: Design Variables

Table 4: Design of Experiments Variables and Ranges

Design Variables	Units	Range	Level
A. Shotgun Profile Height	mm	115-145	15
B. Reinforcement Angle	deg	62-68	3
C. Front Side Rail Inclination	deg	6-12	3
D. Cowl Member Inner Distance	mm	60-100	20

On every virtual experiment, the ratio weight of front module to torsional stiffness has been measured. This way the two important characteristics can be linked in one response value. Analysis of means (ANOM) used to calculate the optimum value of each variable. The objective was to reduce the response ratio, therefore, the “smaller the better” analysis was performed in order for the effect of each variable on the response ratio to be obtained. The signal to noise ratios for each experiment and for each level have been calculated (Peace 1992):

$$\eta = -10 \log_{10} \left[\frac{1}{n} \sum_{i=1}^n y_i^2 \right] \quad (1)$$

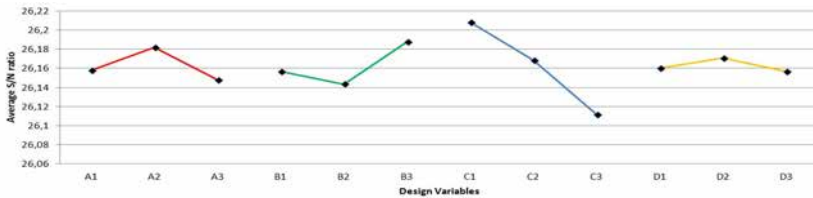


Figure 3: Response graph for each design variable

From the response graph in Figure 3 the maximum value of each design variable corresponds to the selected optimum value from the designated range. Table 4 shows the optimum combination in order for the bigger torsional stiffness value and simultaneously smaller weight value to be achieved.

Table 5: Optimum Combination of the Design Variables

Design Variables	Optimum Design Variables
Shotgun Profile Height	A2 (130mm)
Reinforcement Angle	B3 (68 deg)
Front Side Inclination	C1 (6 deg)
Cowl Member Inner Distance	D2 (80mm)

The optimum combination is translated to 36.909 kg of front module and a BiW torsional stiffness of 15604 Nm/deg. Moreover, the analysis of variance for the S/N ratio has been carried out as indicated in Phadke (1989), in order for the effect of each design variable in the response ratio to be determined. The results can be seen in Figure 4.

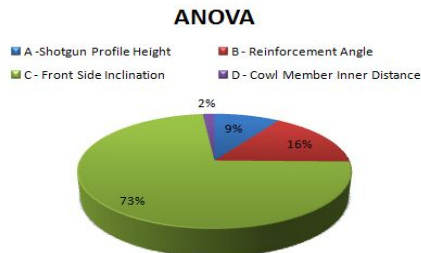


Figure 4: Analysis of Variance of the Experiments

4 RESPONSE SURFACE METHOD

In the frame of this work, a second degree polynomial model has been developed in order to examine the behaviour of the response around the discrete optimum which DoE has identified. With the second degree model it can be identified if the DoE's optimum is global or if there is another optimum, which cannot be identified with DoE due to the fact this method can only indicate results relative to the picked levels of each variable. Therefore new virtual experiments have been conducted. The variables with the bigger influence to the response, according to ANOVA, had been chosen to be altered around the discrete optimum, which has been identified through DoE, while the rest are kept constant.

Table 6: Response Surface Method Experiments

Expt. No.	1	2	3	4	5	6	7	8	9	10	11	12
Reinforcement Angle	66	66	66	66	67	67	67	67	68	68	68	68
Front Side Inclination	6	7	8	9	6	7	8	9	6	7	8	9

The above experiments were used to develop a second order prediction model of the weight/torsional stiffness ratio. The regression coefficients of the second order polynomial equation have been calculated using regression techniques through Matlab.

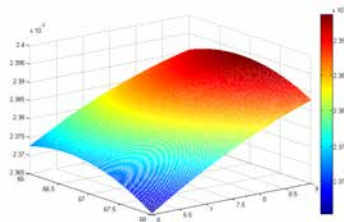


Figure 5: Response Surface Plot

The results showed that in this case the DoE optimum with the RSM optimum coincide. Finally the designer can use the representative second order polynomial equation (1) to take quick decisions at an early stage of the design process regarding the two most influential design variables.

$$y = -0.0000044525x_1^2 - 0.00000086833333x_2^2 + 0.000000783x_1x_2 + 0.000588293749999x_1 - 0.00032831033333x_2 - 0.017141580833140 \quad (2)$$

5 RESULTS

In this work, the front module of an integral designed BiW, had been re-designed under the prism of lightweight and flexibility. The followed workflow is described in Figure 6. Lightweight has been addressed at the level of conceptual lightweight design using an optimization strategy coupling DoE and RSM. Flexibility has been addressed through the manufacturing approach of the parts. Roll forming has been selected as a manufacturing process, as it is cheaper and more flexible than the hot stamping or deep-drawing. It has been achieved a 13.12% weight reduction in the front module and a 2.7% increase in the torsional stiffness of the whole BiW. With the optimization process, weight was kept almost the same (0.7% increase), and the torsional stiffness was further increased by 2.3%. A RSM has been conducted around the discrete DoE optimum to investigate if it is global or local. The result showed that DoE optimum and RSM optimum coincide.

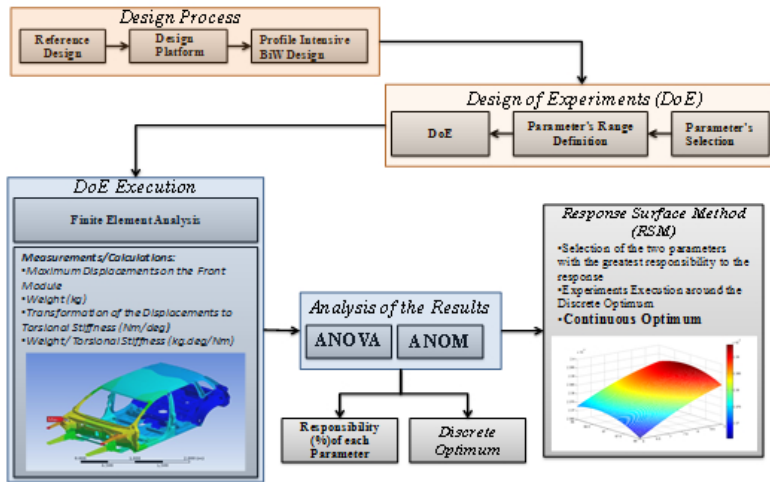


Figure 6: Design and Optimization Workflow

6 DISCUSSION: FURTHER RESEARCH

It is clear that a holistic approach to the design of cars has to be adopted in order to face the environmental and customer's behaviour challenges. Lightweight design and modularity can both help as concepts towards the solution. The work which has been conducted here, should be extended in the rest modules of the car in order to have a complete assessment of the profile design. Work for further research could be to use a multi-material concept for the BiW. Moreover, the impact of a multi-material approach to the production line should be examined. Finally, design maps with the influence of certain design variables to BiW quality characteristics can be developed and used from the designer as a tool to take early-stage decisions during the design process.

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SIMULATION ANALYSIS OF THE SUSTAINABILITY PERFORMANCE OF A SUPPLY CHAIN SUBJECT TO DISRUPTION

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ABSTRACT

In recent years, two main concerns have surfaced in relation to improving manufacturing supply chains; one is their sustainability and the other is their resilience to major disruptions. This first concern relates to the optimal use of ever-scarcer natural resources. Hence, supply chains need to be assessed and re-designed to accommodate this trend and take in to account the triple bottom line of environmental, economic and social measures. The second concern stems from the globalisation of supply chains which increases complexity and vulnerability to major disruptions. To survive, organisations within supply chains must be resilient in the face of such disruptions. This paper's study addresses these two concerns, i.e. sustainability and resilience, by using computer simulations to explore the effects of disruptions on the sustainability performance of a supply chain.

Keywords: supply chain, sustainability, resilience, major disruptions, computer simulations.

1 INTRODUCTION

A number of recent, prominent natural disasters have caused massive damage to businesses, and have caused management to change businesses and industrial operations, supply chains, strategies and structures. For example, the tsunami that struck Thailand in 2011 led to many businesses collapsing because they were unable to adapt and they lacked the knowledge and ability to manage the unexpected situation. Even many of those businesses that did not collapse were forced to close while the impact of the natural disaster was at its peak. Operating supply chains in these circumstances were extremely problematic. As a consequence of such prominent disasters, businesses are now seeking to learn how to cope with future disruptions and academics are looking to point the way for them.

Our paper aims to help by presenting our preliminary work that analyses supply chain sustainable performance when major disruptions impose new ways of working on parts of the supply chain. We carry out a computer simulation study on a supply chain structure taken from the literature.

This paper is divided into four further sections. Section 2 outlines the related literature. The next section (3) describes the supply chain under study, together with the different disruption scenarios. Numerical results are then presented in Section 4, and finally Section 5 provides some concluding remarks and suggestions for further research.

2 OVERVIEW OF RELATED LITERATURE

Managers' increased awareness of the occurrence and impact of natural disasters forces them to adapt and change their organisation's strategy and prepare plans to reduce the impact and protect themselves from disruption (Spillan and Hough, 2003). Some convincing arguments supporting preparation and adaptation exist, e.g. Autry and Bobbitt (2008) state that the company should be prepared by introducing supply chain security orientations which integrate both steps to address security vulnerabilities and risk management approaches to achieving competitive advantage. Securing the supply chain and managing supply chain risks can increase the organisation's ability to

reduce a disruption's impact and to recover quickly. Busch (2011) stated that organisations need to develop capabilities to adapt to climate-related disruptions through resource supply, production process and production distribution. To remain competitive, organisations were advised to invest in securing the resilience of consumer markets, production and supply chains.

To begin with, organisations would need to develop a climate change strategy and planning capability in response to experiencing an unexpected climate surprise. They need to include climate trend in their strategy development because of its unpredictability and its impact on their operations. Nevertheless, many adaptations are reactive rather than proactive ways to mitigate risks and impacts (Haigh and Griffiths, 2011). A study of small businesses shows that entrepreneurs are concerned with crisis planning because of their past experience in crisis events, rather than the existence of a crisis management plan (Spillan and Hough, 2003).

Many researchers have analysed the impact of disasters on organizations and have introduced plans and the concepts of adaption, preparedness and response. Duncan et al. (2011) suggested that to survive businesses should plan and prepare the organisation using the Continuity of Operations Planning (COOP) framework. The framework requires two factors: leaders and resources. Winn et al. (2011) analysed the length and type of impact that natural disasters had in each sector of an industry. They presented the concept of Massive Discontinuous Change (MDC) for organisations to respond to climate impact by improvements in sustainability, crisis management, risk management, resilience and adaptive organisational change. Linnenluecke et al. (2012) dealt with how extreme weather events impacted on adaptation and organisational resilience. They proposed theoretical and practical frameworks related to the organisation's adaptation and resilience to strengthen its capacity to respond to and reduce the impact of extreme weather events. Beermann (2011) categorised the impact of climate change into direct and indirect impact. Pro-active adaptation that focuses on building resilience while combining adaptation and mitigation strategies, is advocated. Therefore, the concept of resilience management (Ponomarev and Holcomb, 2009) can assist in identifying risks and opportunities, coping with climate change both in the short and the long term.

According to Kolk and Levy (2001), the organisation shifts its corporate climate strategy position because of organisation-specific factors, corporate history of profitability and location, market assessments, degree of centralisation and the presence of climate scientists. In this connection, its trends and market activities are examined at company level (internal) and at the company's supply chain level which can assist managers to develop strategies for climate change (Kolk and Pinkse, 2004). Previous studies have focused on the relationship of climate change and sustainable development, and the role of multi-stakeholder partnerships in developing countries on mitigation and adaptation strategies (Pinkse and Kolk, 2012).

From the literature examined, not many studies have shown business strategies are related to extreme weather events. The literature focuses mostly on the government level, disaster impact, organisation preparedness and climate change strategies. Chakravorti (2010) indicates that difficult situations offer rich opportunities for innovative entrepreneurs. Organisations could exploit these opportunities through implementing strategies and operation's activities for making consumer markets, production and supply chains more secure.

3 A CASE STUDY BASED ON COMPUTER SIMULATION

3.1 Description of the Supply Chain

This research explores the effects of disturbances on sustainability performance (Carter and Rogers, 2008) of a supply chain by using a computer simulation. An exploratory study is conducted on a three-echelon supply chain that is based on the automotive industry supply chain presented by Carvalho et al. (2012). Some simplifications were incorporated to run the simulation faster. We evaluate alternative supply chain scenarios that consider both supply chain sustainability and resilience in the face of two major disruptions.

Since the automotive supply chain is very complex, with hundreds of parts, components and materials flowing from hundreds of suppliers, located in different countries, to the automaker, it is critical to establish meaningful features of the supply chain analysed (Srai and Gregory 2008; Brintrup et al., 2012). For practical purposes, only a subset of the supply chain is selected and

analysed here (See Figure 1). Critical tier-1 suppliers are considered, since a delay in the components delivered by these suppliers causes a disruption in the automaker's production line. In turn, tier-2 suppliers are also taken into account since they become critical for tier-1 suppliers. Included in the model are stochastic transportation times (Table 1) and processing times (Table 2) for each node of the supply chain. A triangular distribution is assumed for the times. The final demand was considered to be stable.

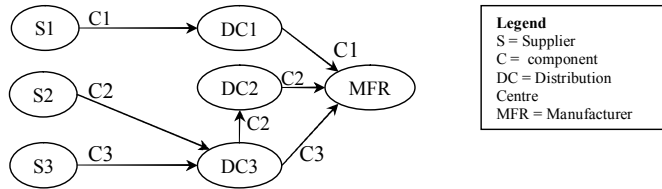


Figure 1: Schematic representation of the supply chain under study.

Table 1: Transport times (triangular distribution) and type of transport.

From	To				Transport type
	MFR	DC1	DC2	DC3	
S1		(5.2, 5.5, 6)			Aeroplane
S2				(5.7, 6, 7)	Lorry
S3				(5.7, 6, 7)	Lorry
DC1	(0.5, 0.55, 0.6)				Small lorry
DC2	(0.5, 0.55, 0.6)				Small lorry
DC3	(0.5, 0.55, 0.6)		(0.5, 0.55, 0.6)		Small lorry

Table 2: Processing times (triangular distribution).

	Product	Administrative processing	Manufacturing or packaging
S1	C1	(0.95, 1, 1.1)	(4.18, 4.4, 4.93)
S2	C2	(2.85, 3, 3.3)	(2.85, 3, 3.3)
S3	C3	(6.65, 7, 7.7)	(3.23, 3.4, 3.91)
DC1	C1	(5.7, 6, 6.6)	(1.11, 1.17, 1.35)
DC2	C2	(1.9, 2, 2.2)	-
DC3	C2	(4.75, 5, 5.5)	-
	C3	(4.75, 5, 5.5)	(0.79, 0.83, 0.95)

3.2 Performance Metrics

To evaluate sustainability, economic, social and environmental performance metrics are considered as outputs of the simulation model. The total production time represents the economic dimension. The social dimension is measured by the number of additional jobs the automaker creates due to growth in the market. Finally, the environmental dimension is represented by carbon emissions of the transportation modes. These metrics are calculated before (initial system) and after each disruption, then compared statistically.

3.3 Simulation Scenarios

In this preliminary study, two major disruptions are compared to the initial, base scenario:

- **Initial Scenario:** this scenario corresponds to the initial configuration (current state) of the supply chain prior to facing disruption.
- **Disruption 1:** In this scenario, the transportation time between DC2 and DC3 increases. We suppose that components have to be re-routed between these two distribution centres because of a natural disaster (e.g., an earthquake or a flood). This is modelled with a triangular distribution with parameters 20, 24 and 26 per entity.

- **Disruption 2:** In this scenario, distribution centre DC2 is closed and hence component C2 must be delivered to MFR from distribution centre DC3 in addition to C3, but using the same small lorry.

4 ANALYSIS OF RESULTS

The system was simulated using ARENA[®] software, and run for 720 hours in stationary state. A total of 57 replications were carried out. The initial supply chain configuration (initial scenario) was studied and statistics collected on the relevant performance metrics (see Figure 2). We observe in Figure 2 that the highest average time an entity spends in a process corresponds to the Administrative Process at distribution centre DC3 (named Adm. Process 5.Queue in the Figure). This process also has the highest number of entities in queue and its resource (Resource 9 in the simulation model) has the highest utilisation rate. This resource has the highest workload since it has to process both components C2 and C3. As a consequence, it seems adequate to increase the number of resources (i.e. people working on these operations). Later on in this analysis, we will observe that some disruptions on other nodes of the supply network will have a negative impact if the number of resources is increased.

For the economic performance, Table 3 presents statistics about the total production time of components C1, C2 and C3 in the system. Component C1 has the lowest time in the system: it flows through supplier S1 and distribution centre DC1, while product C3 has the highest value (flowing through supplier S3 and distribution centre DC3), mainly due to delays in the administrative process of distribution centre DC3. Table 3 also presents statistics about the system's behaviour when the supply chain is subject to the first disruption. A hypothesis test on the means, with a confidence of 95%, shows that there is no statistical evidence to reject the null hypothesis of no difference between the average production times of all products, when comparing the initial supply chain with the one subject to the first disruption (Disruption 1). In other words, although there is an increase of 4% on the average time an entity spends in the system, there is no statistical evidence to say that increasing the transportation time between distribution centres DC2 and DC3 will increase the total processing time of components C1, C2 or C3.

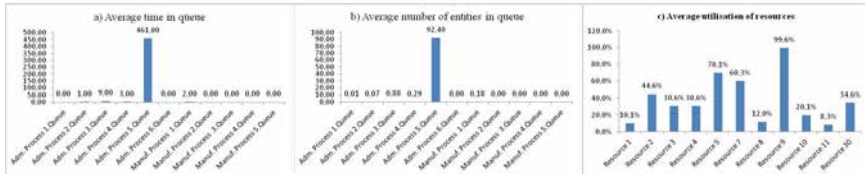


Figure 2: Average time in queue and average number of entities in queues.

Table 3: Economic dimension: Total processing time in the system.

	Initial system		Disruption 1		Disruption 2	
	Average	Half width	Average	Half width	Average	Half width
C1	23.7175	< 0.03	23.7388	< 0.03	23.7623	0.08
C2	482.94	< 15.99	516.90	< 17.05	570.70	50.66
C3	494.03	<16.04	505.18	< 17.09	584.64	50.89

When comparing the initial system with the situation for Disruption 2, the hypothesis test between means (see Table 4) shows that, with a 95% confidence level, there is no statistical difference between the average production times of both configurations. In other words, with a 95% level of confidence, the increase in transport time for component C2 does not impact the total time required to complete its manufacturing.

Table 4: Total processing time in the system .

	Levene test				t-test			
	F	Conf.	T	dof	Conf. (2-side)	$\mu_1 - \mu_2$	St. dev. ($\mu_1 - \mu_2$)	95% confidence interval
Assuming equal variances	1.781	0.185	1.680	112	0.096	6.512.554	387.654	-116.832 1.419.343
Not assuming equal variances			1.680	109.39	0.096	6.512.554	387.654	-116.832 1.419.343

Regarding the environmental performance, i.e. the level of carbon emissions, Figure 3a compares between the different simulation models (initial system and Disruption 1 and Disruption 2). The average quantity of CO₂ due to transport activities in the initial system is higher than in both situations under disruptions, although the transportation times in Disruption 1 and Disruption 2 have increased. A statistical test between means revealed no reason to reject the null hypothesis that both means are the same. The impact of using lower carbon emission modes of transport, e.g. electric vehicles, was analysed. Assuming that the time required by the electric vehicles will be the same, in the case of Disruption 1a reduction of 32,640 kg-CO₂ was observed. Also, when closing facility DC2 (Disruption 2), the reduction in comparison with the initial scenario was about 82,210 kg-CO₂.

Finally, regarding the social performance, Figure 3b compares Disruption 1 and Disruption 2 to the initial scenario. The objective here is to evaluate the performance of human resources in the administrative stages of the supply chain. We observe the actual reduction of 21% (6 posts) on the number of jobs in the supply chain due to the disruption of closing distribution centre DC2. This is clearly a negative impact.

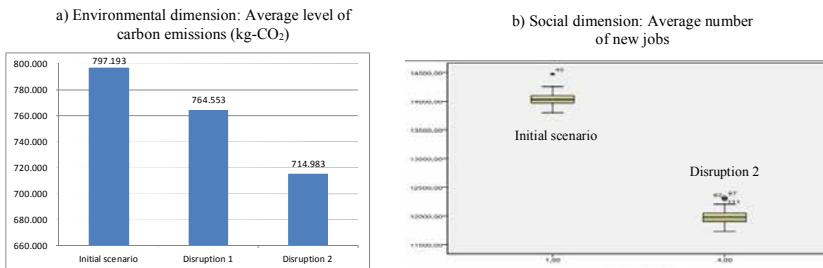


Figure 3: Results for environmental and social dimensions

5 CONCLUSIONS AND FURTHER RESEARCH

From the results in Section 4, it can be concluded that the disruptions have a neutral effect considering the economic dimension of processing time in the system. In a way the system is resilient as the neither disruption impacts on the processing time. The results for the environmental dimension show improvements after both disruptions with a decrease in carbon emissions - this is mainly due to the use of alternative modes of transport with a lower carbon emission rate than those used in the initial scenario. The results for the social dimension show a deterioration in performance with a decrease in newly created jobs, although these could be official paid jobs and some voluntary jobs are generated but not captured by the model.

One of the main limitations of this study is that a hypothesised supply chain with estimated data is analysed. To improve the results it would be necessary to collect real-world data through case studies to fine tune the computer simulations. The implications for theory is a proposed model for testing resilience in supply chains under disruptions taking into account all three sustainability dimensions. The implications for practice are that automotive manufacturers could use similar models to better understand their resilience in the face of disruptions. Future work would need to further test and validate the proposed model with case study and/ or survey methodologies.

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MEASURING INFORMATION SECURITY BREACH IMPACT AND UNCERTAINTIES UNDER VARIOUS INFORMATION SHARING SCENARIOS

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ABSTRACT

This study draws on information theory and aims to provide simulated evidence using real historical and statistical data to demonstrate how various levels of integration moderate the impact and uncertainties of information security breach on supply chain performance. We find that the supply chain behaves differently under various levels of integration when a security breach occurs. The entropy analysis revealed that the wholesaler experience the most uncertainty under system failure and data corruption. This sort of impact-uncertainty information will aid in designing and managing a resilient supply chain poised for minimal breach impact.

Keywords: Supply chain integration, Supply chain disruption, Entropy, Simulation

1 INTRODUCTION

The prevalence of this information sharing paradigm is so rampant that many organisations now cannot do without it. Any compromise to the flow of this vital information would have drastic effect on business performance. Therefore businesses and even supply chains have realised the need to protect this information, even so a significant number have not done enough to protect the Information Systems (IS) that carries this information (Potter and Beard, 2010). With the growing level of sophistication with which miscreants attack various IS, one cannot ignore the issue of IS security. In order to plan for a formidable security strategy, the impact of IS security on supply chain operations must be well understood. Knowing the impact of security breach on an organization and how this affects other members co-owning or depending on the IS would appear to be the requisite foundation to any sustainable information security policy. An information systems security breach for the most part introduces uncertainties or chaos into supply chain operations. Therefore while it is important to understand the cost impact of these breaches, it is more so imperative to establish which aspects of operation or areas in the supply chain are most vulnerable to attack. This will particularly help the supply chain prioritize 'what?' and 'where?' along the supply chain require intensified protection and what appropriate mitigation solution should be adopted. This way, the supply chain can effectively and efficiently plan its operations, optimally prepared for any eventualities. It seems intuitive that impact of security breach and the uncertainties introduced by such breaches on supply chain members would vary depending on the extent of IS dependence. However this has not been evidenced in literature. The extent of IS dependence is conceptualised as the level of information sharing (also called information integration) in the supply chain.

This study applies discrete event simulation (DES) to investigate the impact information security breach has on supply chain performance under various information sharing scenarios. We then use the concept of entropy theory to analyse the degree of uncertainty a breach introduces to the supply chain and its members and how this affects supply chain performance. The performances being assessed are supply chain cost which includes the inventory holding cost, backlog cost and ordering cost, and do not include cost associated with damage to company's image or regulatory fines. This paper is organized as follows. Section 2 presents a brief review of relevant literature. In Section 3, the simulation experiment models are described. Section 4 summarizes the result and discussion and Section 5 concludes the study.

2 LITERATURE REVIEW

2.1 The role of information sharing

As some have suggested that the world is currently in the information age and consequently business should be conducted with this in mind. A business would thrive if it can position itself to leverage as much relevant information as possible. Communication between businesses has greatly improved over the years with the use of Information Systems (IS) such as Inter-organizational Information Systems (IOIS) and huge efforts have been invested into communication with customers as well. Fuelling this agenda is the plethora of investigations into the benefits of communication and information sharing that can be found in literature (Chan and Chan, 2009; Li et al., 2006; Zhou and Benton Jr, 2007).

Li et al. (2006) surmised that the advantage of using IOIS does not only come from efficient transaction processing and improved monitoring and information processing capacity as previous studies indicate, but also from sharing and improved access to key business information. Such key business information have been reported to be demand, inventory, supply lead time and capacity information (Kulp et al., 2004; Yu et al., 2010) and a few others. Huang et al. (2003) revealed in quantitative terms that sharing demand, inventory, and lead time information hold varied benefits depending on the level of information sharing. At the same time, several studies in literature have also shown that the derived benefits only come under the right conditions of: right information being shared at the right time in the right format by the right entities within the right environment (Chan and Chan, 2009). Since security breach in effect would compromise the right conditions of information sharing it therefore appears intuitive that the level of information sharing would affect how an incidence of security breach impact the supply chain and its members. An indication of this has been given by Durowoju et al. (2012b) but this has not been validated. This study aims to validate this and show very clearly in quantitative terms how this happens.

There have been many studies looking at IS risks to an organization and a very few have studied IS risk to the supply chain. However there is yet to be an academic study on the impact of IS disruptions on the supply chain under various conditions. The supply chain condition is defined here as the state of the chain in terms of the level of information sharing (information integration) present, the specific ordering option being used and the structure of the supply chain. It is not evident from literature how this condition mitigates or worsens these risks.

2.2 Entropy assessment of IS risk

While previous studies have estimated information security risks as a function of threat occurrence and the associated financial loss (Rees et al., 2011), only a few have employed the Entropy theory. Although the concept of using entropy as an approach to determine uncertainty has been used in literature by (Frizelle, 2002; Frizelle and Woodcock, 1995; Martinez-Olvera, 2008; Sivadasan et al., 2002), the closest previous studies have come to applying entropy as an assessment tool in security studies has been in data privacy studies such as disclosure risk assessment (Airoldi et al., 2011), measuring anonymity (Bezzi, 2007; Deng et al., 2007). The argument is that since complexity of a system (characterized by the uncertainty of a system) can be measured using entropy approach (Frizelle and Woodcock, 1995; Martinez-Olvera, 2008), and, the little is known about a random variable the more the entropy of that variable, hence the level of entropy of a security breach can be determined once the probability of occurrence is known (Airoldi et al., 2011). The approach is to evaluate security threats using threat occurrence to work out the level of entropy each threat

introduces into the system. This will help identify those threats that are hot spots to guide management decision in selecting appropriate countermeasures and mitigation solutions. While this study is not an optimality study, it provides a useful methodology to security risk assessment from a process based view where financial loss information is not known a priori. Frizelle and Efstathiou (2002) explained that high entropy can impede flow by introducing obstacles that makes supply chain operations less predictable. By inference, security breaches introduce obstacles to the flow of operation and the predictability of these breaches can help evaluate the level of chaos they introduce into the system. Airoidi et al. (2011) demonstrated that using entropy approach in estimating risk is very effective. The mathematical definition of entropy as prescribed by Shannon (1948) is a quantitative measure of uncertainty (Martínez-Olvera, 2008; Sivadasan et al., 2002):

$$H(S) = - \sum_{i=1}^n P_i \log_2 P_i \quad (1)$$

$H(S)$ is the entropy level of the system, defined here as the expected amount of information needed to describe the state of the system S , and P_i is the probability of breach i ($i=1, \dots, n$) occurring, where $P_i \geq 0$

Sivadasan et al. (2002) proposed two models for determining operational complexity under two conditions. First is complexity associated with knowing whether the system is “in control” or “not in control” denoted by the “in or not in control operational complexity index,” OCI (S^{NC}) as shown in equation (2), where P is the probability of being in control. OCI (S^{NC}) is a measure of the amount of information needed to describe the “in-control” or “not in control” state of the system. The closer the probability of incidence is to 0.5, the closer the OCI (S^{NC}) value is to one.

$$OCI(S^{NC}) = -P \log_2 P - (1-P) \log_2 (1-P) \quad (2)$$

Second is the complexity associated with out-of-control states, given that the system is not in control i.e. a breach has occurred. This is denoted by the “not in control operational complexity index,” OCI (S^{NC}) shown in equation (3), where P_{ij} is the conditional probability computed over the “not in control” state with states i ($i=1, \dots, n$) at nodes j ($j=1, \dots, M$). This index is a measure of the amount of information needed to monitor the extent to which the system is not in control.

$$OCI(S^{NC}) = -(1-P) \sum_{j=1}^M \sum_{i=1}^n P_{ij} \log_2 P_{ij} \quad (3)$$

According to Sivadasan et al. (2002), the sum of equation (2) and (3) is the total operational complexity denoted by the operational complexity index, OCI (Stotal). It follows that the higher the operational complexity index, the higher the entropy introduced by the breach into the system and hence the more the associated information needed to manage the system and vice versa.

3 THE SIMULATION MODEL

To illustrate the impact of a security breach, we use the latest information on system failure and data corruption (SFDC) and attack on website or internet gateway (AOW) extracted from the 2012 Information Security Breach Survey (Potter and Beard, 2010). The survey was an online self-select survey with 447 respondent organizations. The respondents were security professionals. We were able to extract information on the average service disruption period caused by the breaches as well as the frequency of occurrence. This information was incorporated into our simulation model as a deterministic model. SFDC was characterised as a breach with average disruption period of five days with an average of three occurrences per year. According to the survey, the average disruption period for AOW was one day with an average occurrence of fifty four times a year. We use these two breaches to illustrate our concept.

The sequence of activities for this study is similar to the one described in (Durowoju et al., 2012b). We would refer the reader to this article for a more comprehensive detail. Information integration is modeled in this study as sharing real time demand, inventory and lead time information. We considered four scenarios of integration, one between retailer and wholesaler only (RW); that between wholesaler and manufacturer only (WM); and one between all three (RWM). The fourth mode is the basic chain with no information being shared (BC) and it is the base mode against which

all other integration levels will be evaluated. However we have improved the reliability of the previous study to 98% confidence level. The entropy scores are calculated using the steps described in (Durowoju et al., 2012a). However we have used quantity instead of cost in our evaluation of uncertainty.

4 RESULT AND DISCUSSION

4.1 Impact of breach

An ANOVA test ($p < 0.05$) revealed that integration mitigates the impact of both SFDC and AOW on supply chain operating cost. Figure 1 shows that SFDC had greater impact than AOW for all information sharing scenarios. The Paired-t test ($p < 0.05$) revealed that there was significant difference in the impact of SFDC between all integration modes. The RWM mode experiences the highest like-for-like increase in cost (27%) while the BC mode enjoys the least increase (at 20%) when faced with SFDC breach type. This seems intuitive as the more the supply chain depends on information, the higher the disruption caused when this information becomes suddenly unavailable. However we see that this does not hold true under AOW breach type. This is because the average service disruption for AOW is one day, which is less than the lead time between the retailer and the wholesaler (2days). Consequently the impact of the disruption is minimised and the effect of higher level of integration lessened. Therefore there is no significant difference between the impact of AOW on a chain with no form of integration (BC) and that with integration between the wholesaler and the manufacturer only (WM). There is also no difference between WM and RWM under AOW breach. This shows that RW (at 2% impact) absorbs the impact of AOW significantly more than any other information sharing scenario. In the case of SFDC breach however, the impact was highest for the full integration mode (RWM).

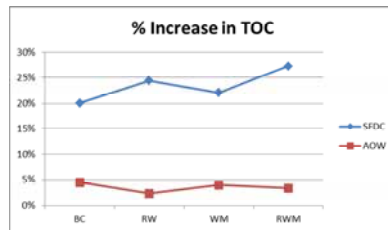


Figure 1: Impact of both security breach on supply chain operating cost

4.2 Relative effect of integration

Using the BC mode as the base mode we consider the relative effect of RW, WM and RWM. This is shown in Table 2. We find that the WM mode performs 4% better than the non-integrated chain and the other integrated chains while the RW chain performed the same as the BC mode under SFDC breach. However under AOW, the RWM mode absorbs 8% of the impact on the BC mode (which is significantly greater than WM and RW at $p < 0.05$), while both WM and RW absorb 6% each of the impact on BC. We see that the mitigating effect of integration varies depending on the breach in question. It is therefore important to profile these breaches and see how they are mitigated by the supply chain condition.

Table 2: Mitigating role of integration on security breach impact

Breach Type	Effect of Integration			
	BC (\$)	WM	RW	RWM
SFDD	360	4%	0%	2%
AOW	313	6%	6%	8%

4.3 Entropy assessment

The SINC is the uncertainty associated with not knowing whether there would be a negative impact or not, that is the 50/50 chance of a negative impact. The closer the probability of in-control (i.e. no negative impact observed) is to 50%, the closer SINC is to 1. Also the further the probability of in-control is from 50% either increasing or decreasing, the closer SINC is to 0. Hence the lower the SINC score the more certain you are of either experiencing a negative impact or not, the higher the score the less certain you are. The SNC on the other hand is the uncertainty associated with the number of countable states of the impact when it is negative. Higher scores occur when the impact is spread over several countable states, and lesser scores occur over few countable states. Consequently the higher the probability of experiencing a negative impact over just one single state or none at all, the closer SNC is to 0. SINC cannot exceed 1 in this case and SNC can exceed 1 depending on the spread of impact.

We see from Table 3 how the uncertainty changes for the performance of the supply chain agents depending on the level of integration when SFDC occurs. The table shows that there is no uncertainty in the way SFDC impacts the order quantity for all agents across all integration modes. However for the retailer we see that the uncertainty experienced is due to that associated with Backlog performance only and that RWM reduces this uncertainty from 0.5 in BC to 0.15. The implication is that full integration helps reduce the chaos introduced by SFDC on retailer backlog performance, while WM increases the uncertainty from 0.5 to 0.68. A further inspection indicates that this uncertainty is only due to SINC uncertainty. The incentive is for the retailer to be fully integrated with the wholesaler and the manufacturer.

For the wholesaler, uncertainty experienced in On-hand inventory performance is only due to SNC and that experience in backlog performance is due to SINC. However, we see that the RW partial integration and RWM full integration reduces the uncertainty associated with on hand inventory performance from 0.43 to zero. However WM only makes this uncertainty worse. The same trend is observed regarding the backlog performance, however the WM mode only made it marginally better instead of worse. This implies that RW and RWM would reduce the uncertainties introduced by the incidence of SFDC for the wholesaler. Therefore the incentive here might be to always integrate with the retailer and not the manufacturer only.

The influence of integration was rather different for the manufacturer. Under the on-hand inventory performance, the uncertainty brought about by SFDC was increased in the RWM scenario while decreased to zero in the RW and RWM scenarios. A similar trend is observed under the backlog performance. RWM worsens the uncertainty and WM reduces the uncertainty. Therefore the incentive for the manufacturer is to integrate with the wholesaler only.

Overall we see that the wholesaler experience the highest level of uncertainty under the BC mode (1.43) and the WM mode (1.55). The retailer experienced the least uncertainty especially under the RWM mode (0.15) the manufacturer consistently experienced more uncertainty than the retailer over all forms of integration.

Table 3: Entropy assessment of SFDC

	RETAILER				WHOLESALER				MANUFACTURER			
	Order quantity				Order quantity				Order quantity			
	BC	RW	WM	RWM	BC	RW	WM	RWM	BC	RW	WM	RWM
SINC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SNC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	On-Hand Inventory				On-Hand Inventory				On-Hand Inventory			
	BC	RW	WM	RWM	BC	RW	WM	RWM	BC	RW	WM	RWM
SINC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
SNC	0.00	0.00	0.00	0.00	0.43	0.00	0.57	0.00	0.00	0.00	0.00	0.26
TE	0.00	0.00	0.00	0.00	0.43	0.00	0.57	0.00	0.15	0.00	0.00	0.26
	Backlog Quantity				Backlog Quantity				Backlog Quantity			
	BC	RW	WM	RWM	BC	RW	WM	RWM	BC	RW	WM	RWM
SINC	0.50	0.57	0.68	0.15	1.00	0.00	0.98	0.00	0.80	0.97	0.72	1.00
SNC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TE	0.50	0.57	0.68	0.15	1.00	0.00	0.98	0.00	0.80	0.97	0.72	1.00
Total	0.50	0.57	0.68	0.15	1.43	0.00	1.55	0.00	0.95	0.97	0.72	1.26

4 CONCLUSION

We have only tried to show that integration mitigates the impact of security breach and demonstrate how these breaches introduce uncertainties in the performance of supply chain agents. We have shown that the impact of a breach varies depending on the type of breach and the level of integration. While it is important to understand cost impact, the uncertainties associated with this impact is also important to keep in mind. Depending on the state of the supply chain this impact can vary depending on the severity of the disruption caused by the breach and entropy theory has been applied to understand where the vulnerabilities lie. Future work would be to complete the entropy assessment of the other breach types and also investigate the role of ordering policy in mitigating the impact and uncertainty of these breaches.

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SUPPLY CHAIN RISKS: AN AUTOMOTIVE CASE STUDY

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ABSTRACT

The supply chain is a complex system exchanging information, goods, material and money within enterprises, as well as between enterprises within the value chain. An effective supply chain management contributes to large corporate profits and it is therefore a valid path to reinforce the enterprises' competitiveness. However, supply chain is exposed to influences from undesirable factors both from the outside environment and the entities in the chain. Moreover, industrial trends towards lean production, increasing outsourcing, globalisation and reliance on supply networks capabilities and innovations, increase the complexity of the supply chain. Therefore, managers need to identify, and manage risks, as well as opportunities, from a more diverse range of sources and contexts. This paper contributes to identify and categorise supply chain risks based on a literature study and an automotive manufacturer's viewpoint. The empirical results indicate suppliers and raw material prices as the major internal and external potential risks.

Keywords: supply chain management, risk assessment, automotive industry

1 INTRODUCTION

Supply chain is a complex system which exchange different information, goods, material and money internally within the enterprise or externally with other companies. Firms' profits can depend heavily on its supply chain management and the supply chain management is a valid path to reinforce the enterprises' competition (Li and Xie, 2009). However, supply chain is easy to be influenced by undesirable factors, both from the outside environment and from the entities in the chain (Cunlu and Peiqing, 2006). Furthermore, changes in organisational structure lead to complexity in the supply chain and increase the risks in it (Pereira, 2009). Take an action regardless of the whole system, cause supply chain instability and interruption by financial losses, loss in demand, damage in security and health and finally bad reputation (Hui-hui, 2010, Thun and Hoenig, 2011). One could assume that the more complex the interactions and the tighter coupled the supply chain, the more prone the supply chain is to unexpected, untoward events (Wagner and Bode, 2006). Correspondingly, supply chain disruptions can have significant impact on a firm's short-term performance and long-term financial performance (Tang, 2006).

Production risk concerns any undesired consequences in the production process, such as the possibility of danger, damage, loss and injury (Harland et al., 2003). In other words, Royal Society (1992) risk as *"the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge"*. Risk management in supply chain has become crucial due to industrial trends in today's market such as increase in outsourcing, globalisation, reliance on supply network for specialised capabilities and innovation. Supply Chain Risk Management (SCRM) is a process of identifying potential risks of entire supply chains, analysing and determining characteristics and sources in order to manage the risks (Neiger et al., 2009) which can affect market, operational and financial performance. Companies are mostly aware of supply chain risks but owing to underestimation of the impact and lack of knowledge about tools, managers neglect to implement appropriate instruments (Wu, 2010). The first and the most important step in SCRM is risk

identification and supply chain expansion makes risk identification a challenging task (Karningsih *et al.*, 2010).

The focus of this paper is to by a literature frame of reference and an empirical study identify and distinguish the internal and external supply chain risks for a large automotive manufacturer of today. Consequently, identified aspects are ranked by a performed survey at a heavy automotive industry manufacturer. Finally, the obtained results are discussed in respect to both literature and the empirical findings, in the effort of acting proactively and minimising the risk of incidents within the supply chain.

2 RESEARCH METHODOLOGY

This paper is based on structured literature review about risks of supply chain management as well as conducting a survey at a heavy automotive manufacturer: Volvo Construction Equipment in Eskilstuna, Sweden. Automotive manufacturing was chosen due to the inclusiveness and complexity of supply chain in such industries.

Based on a review of 21 articles, 16 different risks were identified and divided into 2 main categories: internal and external risks. Internal risks imply as interactions within a company which can be controlled whereas external risks occur due to interactions of a company with its environment which are out of its control. Based on the literature review, a questionnaire with 16 question about each risk was disseminated to the company. The questions were formulated so they could be measured by a five-point Likert scaling system, ranging from “very low” to “very high” in order to analyse the risks according to each participant’s viewpoint. 10 respondents from the logistics department and 9 respondents from the purchasing department at the company were involved to answer the questionnaire. The respondents were inquired to measure the vulnerability of each risk in the supply chain regarding to their experience, from very low to very high i.e. from 1 to 5. A statistical analysis was thereafter conducted on the answers by SPSS software, in order to rank the risks. As this type of information follows a normal distribution, a mean and standard deviation test (Motulsky, 1995) was used to identify each risk’s importance.

3 SUPPLY CHAIN RISKS

Clustering supply chain risks into different categories has been done previously by number of scholars, for instance studies by Harland *et al.* (2003), Kleindorfer and Saad (2005), Gaonkar and Viswanadham (2007), Li and Xie (2009), Narasimhan and Talluri (2009), Tang and Nurmaya Musa (2011) and Thun and Hoenig (2011).

Supply chain risks can be divided into two main groups: internal risks within a company such as machine breakdowns or IT problems and external risks such as natural disasters or man-made activities. Internal risks generally have higher possibility to occur whereas external risks generally have a higher impact. Perspectives of risk could be about organisational buyer behaviours, procurement and supply, purchasing strategy selection, and strategic risk, such as outsourcing risk, environmental risk and e-business risk (Harland *et al.*, 2003). According to supply chain system constitution, risk sources by supply chain entity lie within the boundaries of the supply chain parties and range from labour or production to IT-system uncertainties (Cunlu and Peiqing, 2006). IT disruptions is caused by increasing in usage of internet for sharing information or using enterprise resource planning solutions like Oracle and SAP. It leads to reduce the transactions’ time and inaccuracy, although may cause information distribution (Tang and Nurmaya Musa, 2011).

Trends toward lean production have led also to take more risks in planning, producing, transportations, packaging (Thun and Hoenig, 2011). Moreover, global sourcing is usually associated with increased uncertainty as well as poorer transparency and visibility. Globalisation and outsourcing obviously have hidden cost and managerial difficulties like import/export duties, tax policy or fluctuation in currency exchange rate in partner country (Tang and Nurmaya Musa, 2011).

Complicating factors that have to be tackled are longer lead-times due to long routes of transportation, which causes loss in material cost and increase the time of transportation. By the same token, rational usage of transportation space is another thing to be considered. Besides, supplier should be flexible enough to respond to any order quantities and rush orders (Schoenherr *et al.*, 2008). More issues to highlight are reliance on critical infrastructures, financial instability, lack of ability to

settle payment, inappropriate investment and having large capital tied up. The latter is a common problem in low cost countries which should be avoided.

Jiang *et al.* (2009) argued that most common risks in supply chains are based on short-term uncertainties of certain events, which could be called production risks such as equipment failures, lack of proper documentation to clear customs, quality problems due to excessive employee turnover, sudden changes regarding to emergence disruptions, reduction or stop in production or lack of key personnel. Wagner and Bode (2006) defined a model which incorporates three supply chain risk sources: demand-side, supply-side, and catastrophic. Demand-side risks result from disruptions emerging from downstream supply chain operations. This includes on the one hand disruptions in the physical distribution of products to the end-customer with particular issues in transportation operations and the distribution network. On the other hand, demand-side risks can originate from the uncertainty surrounding the random demands of the customers which is also called operational risks (Narasimhan and Talluri, 2009). These kind of risks implied as product sales rate, respond to demand's variation, forecast demand, flexibility to order quantity changes, keep customers satisfied by new product and increasing the price. The last risk source deals with natural disasters, economic and socio-political instability and terrorist attacks.

Supply risks associate with suppliers adequate and their ability to fulfil the product quality and quantity in terms of delivery punctuality and on budget which both have high probability and impact. Considering the requirement of single or multiple sourcing is another risk in this matter. However, financial problems, capacity, lack of flexibility in production and design are the others. Supply-side risks reside in purchasing, supplier activities, and supplier relationships. These include supplier business risks, production capacity constraints on the supply market, technological changes, innovation or new designs which these cause disturbance for suppliers. Capacity constraints or shortages as well as poor logistics performance derive from unsolved problems in the supplier's production and operations management. Furthermore, poor quality in the purchased products or services is a significant risk. The inability of suppliers to adapt to technological or product design changes may have detrimental effects on the customer's costs and competitiveness (Wagner and Bode, 2006). Additionally, dealing with suppliers' labour problems is a timely and important managerial topic, because these problems are exposing the global supply chain to be harmed by business risks. Reduction of supplier makes the supply chain unstable and increases the risk of supply interruption (Pereira, 2009).

Another type of risk is the management risks. Making wrong decision in different situation such as choosing unsuitable partners cause some problems in production which lead to lack of capability to provide customer demands (Wu, 2010). In the supply chain, numbers of partner companies are connected to each other which all the enterprises have to cooperate, control and monitor one another. Another type of risk, therefore arise which called "Risk of supplier becoming competitor"(Neiger *et al.*, 2009). If more companies get involved, then the chain becomes larger and more complex and therefore the further companies should be reliable, responsible, and dependable, otherwise the entire supply chain will encounter the risk of supplier's supplier.

External environmental risk sources comprise any uncertainties arising from the supply chain-environment interaction which are referred to the major disruptions caused by natural and man-made disasters (Narasimhan and Talluri, 2009). These risks were recognised by the focal firm, and may be the result of accidents (e.g. fire), socio-political actions (e.g. fuel protests or terrorist attacks like the 9/11/2001 World Trade Centre attack), civil unrest, political instability, war, and social risks, economic disruptions, geographical reasons like extreme weather, or natural disaster like earthquakes, tsunamis, droughts, hurricanes, and floods. They have low probability to happen but if they do, it will have huge effect on supply chain. The negative consequences of catastrophic risk on supply chains are obvious since production facilities and transportation are highly vulnerable to natural disaster. Moreover, market risks such as instability in cost of raw material or products in market or change in market opportunities and economical risks like economic unsteadiness such as fluctuations or rapid growth could affect the company's supply chain (Thun and Hoenig, 2011).

As a result of the literature review, 16 main risks were identified and classified into internal and external aspects, with the internal risks being: machine breakdowns, supplier failure, supplier quality problems, delivery chain disruptions, change in customer demand, transportation failure, malfunction of system, import or export restrictions, technological change, accident and increasing customs duty

and the external risks being: increasing raw material prices, natural disaster, oil crisis strike and terrorist attack.

4 EMPIRICAL FINDINGS

In the performed survey at Volvo CE in Eskilstuna, 16 different risks have been analysed by 19 people from logistics and purchasing department. A questionnaire with 16 question about each risk was disseminated to be filled based on participant's viewpoint and experience. The respondents were inquired to measure the vulnerability of each risk in the supply chain regarding five-point Likert scaling system ranging from 1 to 5 i.e. very low, low, moderate, high and very high. and the corresponding scales were calculated in each risk aspect. According to the conducted survey, 93.75 % of the risks have more than 50% of likelihood to occur. Table 1 represents the final ranking of the variables. A statistical analysis was consequently conducted on the answers by SPSS software in order to rank the risks. As this type of information follows a normal distribution, a mean and standard deviation test (Motulsky, 1995) was used to identify each risk's importance.

Table 1: Descriptive statistics of risks in Volvo CE

Risks	N	Mean	Standard Deviation	Standard Error Mean
Increasing Raw Material Prices (External)	19	3.63	1.065	0.244
Machine Breakdowns (Internal)	19	3.63	1.012	0.232
Supplier Failure (Internal)	19	3.58	0.838	0.192
Supplier Quality Problems (Internal)	19	3.58	0.838	0.192
Delivery Chain Disruptions (Internal)	19	3.47	0.905	0.208
Change In Customer Demand (Internal)	19	3.42	0.838	0.192
Transportation Failure (Internal)	19	3.32	0.946	0.217
Malfunction of IT System (Internal)	19	3.16	1.119	0.257
Natural Disaster (External)	19	2.84	1.302	0.299
Oil Crisis (External)	19	2.79	1.032	0.237
Import or Export Restrictions (Internal)	19	2.79	1.084	0.249
Technological Change (Internal)	19	2.79	0.855	0.196
Accident (Internal)	19	2.74	1.046	0.240
Increasing Customs Duty (Internal)	19	2.74	0.872	0.200
Strike (External)	19	2.63	1.257	0.288
Terrorist Attack (External)	19	2.26	1.147	0.263

As shown, "Increasing raw material prices" risk has the highest rank in the company's point of view and "Terrorist Attack" risk has the lowest one which is the only risk under the 2.5. "Increasing raw material prices" and "Machine breakdowns" have the same mean value, but the first risk has a highest standard deviation indicating it to have a higher likelihood. The most considerable risks ("High" risk) are "Increasing raw material prices", "Machine breakdowns", "Supplier failure" and "Supplier quality problems", all given the risk value of more than 3.5. "Delivery chain disruptions", "Change in customer demand", "Transportation failure", "Malfunction of IT system" were given a mean risk value between 3 to 3.5, indicating a "moderate" risk. Finally "Natural disaster", "Oil crisis", "Import or export restrictions", "Technological change", "Accident", "Increasing customs duty", "Strike", "Terrorist attack" were all given a risk value between 2 and 3, considered as "Low" importance risks. According to the results, there are no risks related to "Very High" or "Very low" importance.

5 DISCUSSION

According to Table 1, 50% of the “high” risks consist of suppliers issues, which means selecting right suppliers is a key contribution in managing the supply chain. On the other hand, increasing raw material prices is the significant risk in supply chain in the company’s standpoint, which is uncontrollable although forecasted and planned in advance.

Considerable vulnerability in supply chain may be related to the organisational structure. When the supply network complexity increases, risks increase as well (Harland *et al.*, 2003). Changes in raw material prices is considered the highest risk for the supply chain while supplier failure and supplier quality problems has the second rank. Thun and Hoenig (2011) asserted that supplier quality problems must be regarded as the most critical risk since they have both high probability and high impact. This study therefore, have approximately the same result to reveal that supplier issues and increasing raw material prices were highly influential parts of supply chain risk that can be controlled and managed by supply chain partners. Supplier failure and a malfunction of the IT system are seen as severe problems but are less likely to occur in Volvo’s viewpoint. The highest probable risks are observed in terms of increasing raw material prices, customer demand changes, and delivery chain disruptions. Wagner and Bode (2006) stated that risk derived from supply-side risk sources is elevated by supplier dependence, single sourcing, and global sourcing. Supplier dependence obviously amplifies the threat from poor quality, supply shortages, sudden demise of one of these suppliers and poor logistics performance but it could decrease the risk exposure to catastrophes. Single sourcing approach seems to be less uncertain since it is usually aligned with a closer relationship that might absorb some of the supply-side risk. Global sourcing boosts particularly risk stemming from the upstream supply chain. However, according to results by (Li and Xie, 2009) selection of vendors and selection of clients play the key roles among all the factors and bad record of partners is the most outstanding risk factor. Harland *et al.* (2003) notes that the current business trends of increasing product/service complexity, outsourcing, globalisation and e-business that have led to more complex, dynamic supply networks, have resulted in risks shifting around supply networks. In order to lessen these risks establishing the monitoring mechanism based on the cooperation record can enhance the mutual trust and strengthen communication between partners. Another thing that can lower these types of risks could be the climate of the job for workers, Jiang *et al.* (2009) stated that since workers show lower job commitment, greater job dissatisfaction and higher turnover, suppliers’ production capacity and quality levels are more at risk, which seriously threatens the global supply chain’s performance.

Changes in customer demands can have a “moderate” risk for the supply chain. Firms that are dependent on some customers are exposed to a risk of suffering from the detrimental effects of demand volatility and poor downstream information. However this sort of risk is also related to supplier failures due to the fact that dependence on suppliers generally implies a lack of switching options and weak negotiation power. A firm is therefore, less flexible on the supply side and consequently less capable of dealing with volatile demand and poor information from the demand side. Moreover, inventory level set is the most outstanding effect risk factor and strengthen honest culture and establishing the mechanism of risk-sharing. Incentive leads avoiding this situation effectively.

6 CONCLUSION

According to the empirical data, internal risks are the driving force in the supply chain although “increasing raw material prices” is considered to have the most extreme consequences. In the last decade, emergence catastrophe has occurred around the world such as Japan’s earthquake in 2011, economic crisis in 2009, etc. which affected the world business, most of the times cause financial loss. Internal adverse factors in business which are also happened around each company and make supply chain vulnerable in term of competitiveness, complexity, globalisation and product variants. Hence, the role of supply chain management become more influential due to responsibility to make various decisions in different situations including choosing the right supplier or strategy beside of synchronising the members inside the company and relations between supply partner. The trend toward lean production by reducing the inventory, outsourcing, globalisation in order to capture more markets and concentrating on efficiency, make supply chain network more complex which lead to take more risks in planning, producing, transportations, packaging. Managers need to identify, analyse

and manage risks, as well as potential opportunities, from a more diverse range of sources and contexts. When risk issues and its impact on the performance measures is not considered in supply chain management, suboptimal results and inconsistent processes are inevitable. In order to prevent risk comprehensively, risks need to be identified and actions have to be taken before the incident. Evidences depict that neglecting the SCRM lead to irrecoverable disruption such as reduction in profitability and loss in costumers.

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A COLLABORATION FRAMEWORK TO SUPPORT DECISION MAKING IN NEW PRODUCT DEVELOPMENT WITH THE SUPPLY CHAIN

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ABSTRACT

Management use the supply chain features more frequently, as the increasing rate of product introductions demands more efforts from a business to deliver new products effectively and efficiently. To produce products at the targeted cost, time, and quality, the supply chain must be aligned with product development processes. This will allow manufacturing firms to overcome problems such as (partially) failed product launches due to the lack of timely provision of parts and systems caused by insufficient capacities in the supply chain. With integrated New Product Development (NPD) and Supply Chain Management (SCM), enterprises have the benefit of increased supply chain capability, thus increasing the effectiveness of new product introduction and improving their overall performance. In this research, the authors have tried to link NPD of an automotive manufacturer to its global network of suppliers. The integration points in the integrated NPD and SCM framework will provide guidelines to identifying where critical decision are made in collaboration with the supply chain.

Keywords: New product development; Collaboration; Decision making; Supply chain management

1 INTRODUCTION

New Product Development (NPD) and Supply Chain Management (SCM) are business priorities in manufacturing firms. In the current manufacturing environment where there is increasing pressure on Research and Development (R&D), better NPD and SCM are identified ways to becoming more competitive. At the same time, technology life cycles have shortened so much that there is no time and cost available to bear the load of piles of inventory. The above issues are more significant for time-to-market products. Therefore, to be more competitive in the marketplace, firms have to focus more on NPD-SCM integration. NPD gives an opportunity for transforming market requirements and engineering technologies into marketable products (Ulrich and Eppinger, 2011), whereas SCM is an integral part of any firm for all the stages from customer requirement to product delivery hence suggesting the importance of NPD in SCM process (Soni and Kudali, 2012). Along with tools from project management and concurrent engineering, different tools have been used to assess and integrate customer needs into product design.

It is not an easy task to link these two attributes of a business and could lead to problem. The other issue which has been raised by the literature review is that until now there is no evidence of detailed framework which provides effective linkage between SCM and NPD. In almost every business sector such frameworks and tools are needed to make the impact of linking SCM to NPD (Pero et al.,

2011). Hence the authors aim to investigate and analyse the key decision making points within integrated supply chain functions allowing to identify various functional requirements in the whole period of a NPD project. There is no doubt that SCM and NPD are closely related to each other, for the product to be designed with the help of Information and Communication Technologies (ICT) tools which then distribute the product development tasks within the supply chain features. Effective SCM is the only way which makes it possible to design, organize, and execute all the activities from planning to distribution along the entire supply chain. The other benefit of SCM is that it helps organise and use more productively the network of suppliers, manufacturers and distributors (Zhang et al., 2006). The literature which shows the lack of NPD-SCM integration, and the analysis which has been done by authors while keeping this business requirement in mind, have been discussed in this paper.

2 LITERATURE REVIEW

The literature suggests that most SCM models and methods developed by previous researchers, assume that product design decisions have been already taken. However, it has been recently observed that there is a demand arising for the coordination of SCM and NPD (Primo et al., 2007). The approach called “design for supply chain management” suggests that the NPD-oriented way of business can identify the supply chain constraints at the early stages of product development. All the supporting models of the NPD-oriented approach are based on either simple bill-of-materials (BoM) or more sophisticated product architectures. In the existing tools available, researchers used product architecture-based models more frequently than simple BoMs. Product architecture generation is the process by which the function of the product is allocated to physical components. It has been argued by Ulrich and Eppinger (2011) that the product architecture, rather than simple BoMs, will help in addressing more effectively like the trade-offs between product, process, and supply chain design. Many existing models have shown the relationships between product architecture characteristics and supply chain decisions (Van Hoek et al., 2010). Some other models reported in literature help in dealing with the selection of the appropriate sourcing strategy (Soni and Kodali, 2012); And other models focused on the placement of the differentiation point in the supply chain.

Through a recent literature survey carried out in this project, there is no evidence of comprehensive frameworks which deal with NPD and SCM alignment. However, management still needs tools which explain the impact of new product introduction on the supply chain, and vice versa. The tools should provide guidelines to management team depending on product features and enable them to identify the supply chain decisions that lead to high NPD performance. Base on the limitations in current technologies, two research questions in have been identified which form the focus of this project (as shown in Figure 1).

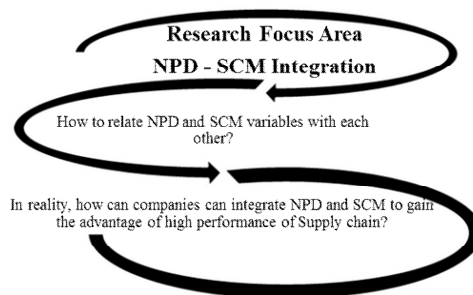


Figure 1: Research questions that form the research focus in NPD – SCM Integration

For analysing these research areas, the authors have followed the research path in two phases. In a first phase, the current available literature dealing with NPD-SCM integration and their dependencies and formulation of generalised features of the framework was analysed. This identified features of generalised frameworks, developed at an early stage of the research process, improved understanding

of how in supply chain the new products are being affected. In the second phase, an exploratory case study of OEM and Tier1 supplier relationship was conducted, to identify the key decision making points. On the basis of these new findings, the features of generalised framework were analysed and then finally combined with the findings from the literature and the case study to develop the alignment framework and to formulate four key decision making points indicating the relationships between NPD and SCM variables.

The alignment of SCM and NPD should lead to an improvement in the performance of both NPD and the supply chain, which can be measured in many different ways (Sharifi et al., 2006). In particular, performance is tightly linked to the concept of delivered variety. Delivered variety refers to the number of different products a company actually delivers to the market and must be defined in relationship to efficiency and responsiveness. If the delivered variety does not keep pace with the customers' orders, then the firm is facing operational problems such as backlogs, stock-outs or overstocks. If it matches, then performance is expected to be high (Carillo and Franza, 2006).

3 METHODOLOGY TO INTEGRATE PRODUCT DEVELOPMENT AND SUPPLIERS

The idea of integrating product development phases in the supply chain has been proposed by the authors (Hasan, Shah and Gao, 2012) and it has been observed that there are so many different aspects existing, including the one which the authors focussed more, i.e., to identify the key decision making points in Original Equipment Manufacturers (OEM) and supplier relationships.

By conducting the industrial investigation in ABC Company (a large international automotive OEM, operating globally and has more than 160,000 employees in 70 plants worldwide with thousands direct and indirect suppliers), the contact has been established with one of their direct local supplier named XYZ Ltd. The XYZ company supplies casting parts for their car engines body to ABC Company. After analysing the complete OEM's product development process in line with the supply chain, it has been observed that when the ABC Company asked their Tier1 supplier for the quotation through RFQ (Request for Quotation) document, the supplier goes through the processes shown in Figure 2.

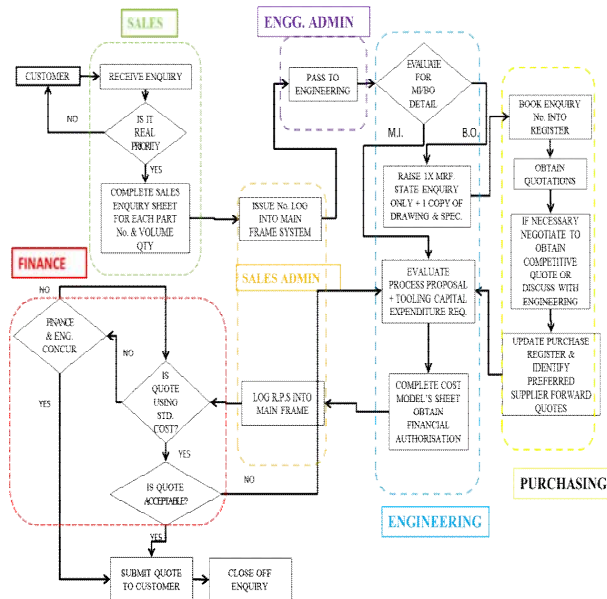


Figure 2: XYZ Company's Early Stage Processes When Collaborating with ABC Company.

The analysis of new product development in OEM (ABC Company) and its Tier 1 supplier (XYZ Ltd) has been done in this research. The main aspect which has been identified in the analysis is feasibility. The analysis has been performed to identify their new product development processes as the whole car engine assembly, which is an integrated view of ABC Company and XYZ Ltd.

4 DECISION POINTS IDENTIFIED AND USED TO TEST THE FRAMEWORK

The whole supply chain has been evaluated for Tier 1 suppliers of the OEM, i.e., the companies which provide manufacturing capability. Based on the concept of Kenneth Preiss (1999): about the process, it has been observed that for any business process, the following decision points need to be clarified which define the process more functionally. These features are as follows: Function, Control, Input and Attributes. Figure 3 shows the basic supply chain activity flow starting from customer requirements and ending with product reaching the customer. The figure also highlights the detailed activity flow described in a functional way namely NPD, Production and Delivery/Distribution.

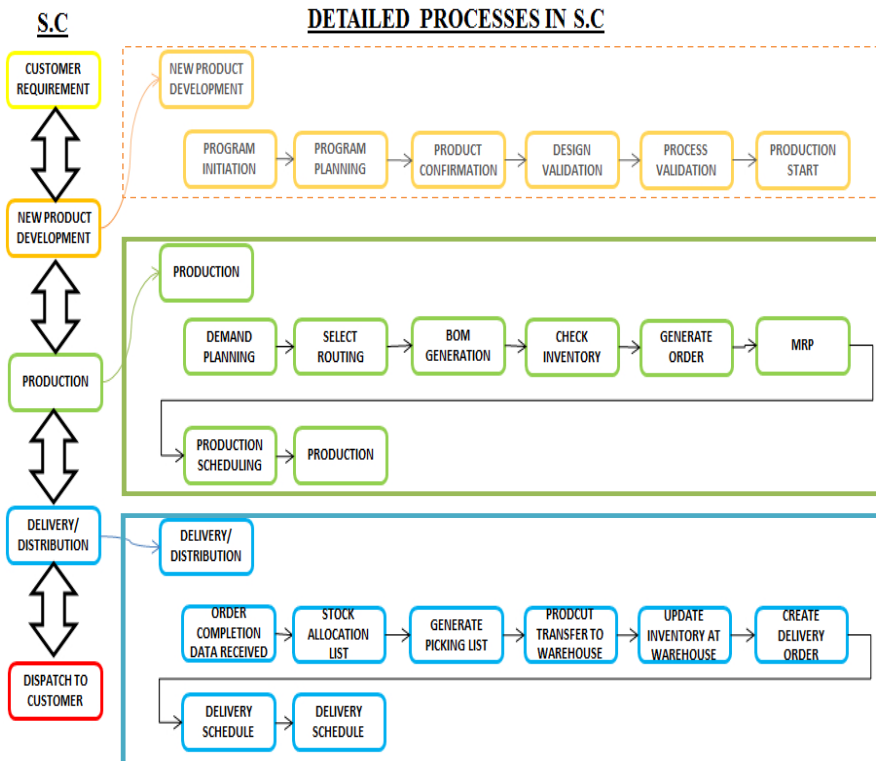


Figure 3: The Supply Chain Processes with Detailed Sub-processes Used as Case Study

The Kenneth Preiss model concept has been kept in mind while the decision point analysis has been done in the selected domain for case study (i.e., production and delivery/distribution). By looking at the basic framework of supply chain in which product starts from customer requirement and goes to the final stage where it has been delivered to customer in a market, there are many steps that a product has to go through before goes to the end of the production line. While transforming those steps in a same Kenneth Preiss model of process, the following features have been categorised in the Figure 4.

PRODUCTION		DELIVERY/ DISTRIBUTION		
		Warehouse	Logistics	Retailer
Functions	Demand Planning Select routing BOM generation Check Inventory Generate order to production department MRP Production Scheduling Production	Order completion data received Stock allocation list check Generate picking list Product transfer to warehouse Update inventory at warehouse	Received update of inventory Create delivery order Delivery schedule	Delivery schedule Delivery
Control	Market Trend Report. Customer Requirement Logistics Urgent release Orders	Production order Warehouse demand	Market requirement Distributors requirement	Sales analysis Trend analysis
Input	Concept development Market Survey Inventory level Cost Market analysis	Inventory level Urgent customer demand	Customer requirement Urgent customer demand	Market requirement Seasonal demand
Attributes	Batch Size Stoppages Shift Time Pull or Push Actions on Input/output	Queue to hold orders for pick Activity to pick Queue to hold order for delivery Picking quantity Queue to hold goods ready for sale Activity to model customer demand Activity to generate urgent orders Goods for delivery	Batch size Duration Priority	Customer demand Maximum arrival First arrival Interval Lot size

Figure 4: Decision point analysis in production and delivery/distribution of ABC Company – XYZ Ltd.

5 CONCLUSION

The goal of this research is to develop a methodology for effective NPD-SCM integration for new product development. So far the early results of integration has been achieved and the results of manufacturing side has been analysed also where different key decision points have been identified. By looking at the bigger picture, where OEM's product development processes linked by Tier 1 supplier's product development processes, it has been identified that different key decision making points exist and by analysing these key decision points, the framework may be redesigned, in order to transform this into a generalised framework including all the business aspects.

In the future, other decision points such as feasibility, time, cost and performance might be merged within this proposed methodology. Some of the further work required, covers the analysis of

developed model in various extended enterprise scenarios, identifies effects of various variables in the product development process on the performance of supply chain management and vice-versa, and characterises the model for accommodating different business processes of collaborating partners in the product development process.

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MIXED-MODEL PRODUCTION SYSTEM DESIGN FOR AIRCRAFT ASSEMBLY

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ABSTRACT

With the advancement of flexible fixture and flexible tooling, mixed production has become possible for aircraft assembly as the manufacturing processes of different aircraft/sub-assembly models are similar. However, due to the low volume and complex constraints of aircraft assemblies, how to model the problem and produce a practical solution has been a great challenge. To tackle this challenge, this work proposes a methodology for designing the mixed production system, and a new scheduling approach is proposed by using combined backward and forward scheduling methods. These methods are validated through a real-life industrial example. As a result, the number of workstations is reduced by 50%, and the cycle time for making a fuselage is reduced by 38% by using the new mixed-model system.

Keywords: Mixed-model, Aircraft assembly, Production system design

1 INTRODUCTION

Aerospace enterprises are striving for flow-line production as occurred in automotive industry in order to improve their productivity. However, flow-line production is mainly useful for large volume production but may not be suitable for aircraft assembly considering the low volume and high variety nature in aerospace production. With the advent of flexible tooling, mixed-model production has been identified as the possible solution for aircraft production, as mixed-model production system can produce a number of distinct but similar products on the same production line (Jin et al. 2012). Obviously, designing such a system is not an easy task, because aerospace production is characterized by low volume, large scale, large number of operations associated with varied processing times, labour intensive, parallel machines, and many constraints such as tooling/precedence/dependency/routing constraints.

Currently, dedicated workstations are utilized to manually assemble each individual panel separately. As different panels (even for the same aircraft model) are associated with significantly varied processing times, some workstations have to be idle for waiting for the other panels. This makes the system have a high level of WIP (work in progress), and an inefficient workstation utilization. In addition, the current system impedes the deployment of automation because of the lack of division of work. A mixed model production line, which produce different product models in the same line, will be suitable for the aircraft panel assembly production, in order to reduce the manufacturing cost. In literature, the research in mixed production mainly focused on two types of production systems, i.e., job shops and flow lines. In job shops, most research is trying to generate an optimal scheduling strategy for minimizing setup time or make span of production systems to cope with a large number of product models (Heike et al. 2001; Khan and Day 2002; Boysen et al. 2008). In flow lines, most literature focuses on long to medium term problems in assembly production system design with only 2-3 product models for large volume industries, such as the automotive and chemical industry (Heike et al. 2001; Bukchin et al. 2002; Becker and Scholl 2006; Petrovic and Duenas 2006). There has been very few papers yet studying the unique aerospace production system which is neither a job shop or a flow line due to the dependency in between different product models (e.g. four different panel assemblies for making a fuselage barrel). There is a great gap in between the academic research and

industrial applications (Boysen et al. 2008). Existing academic algorithms which most utilizes simplified models cannot be applied to industrial problems.

To fill the knowledge gap, this work is to propose a practical methodology for designing mixed model flexible assembly lines for aircraft assembly. This method includes three major steps, i.e. work content analysis, capacity requirement analysis and workstation layout design, and scheduling. The methodology is validated through a real-life industrial example. The productivity and cost gains resulted from the mixed-production system are presented in comparing to the current production line.

2 PROBLEM STATEMENT

Figure 1 shows a schematic diagram of a production line for producing fuselages. It can be observed that the production line involves a flow-line system as well as some parallel machines. Note that the figure only shows a general process, and it would be much complex at each stage for producing multiple aircraft models. In the herein paper, we are targeting at the panel assembly stage, where a number of different panels are produced according to downstream process demands. Currently, dedicated workstations are employed for panel assemblies in the current production system. For example, one fuselage of an aircraft model is composed by 4 barrels and each barrel is composed by 4 panel assemblies, so there are 16 workstations dedicated for producing the 16 panel assemblies, and the operators are cross trained and can work on different workstations. Although these panel assemblies are similar in shape and operations, the work for each panel, which need to be processed up to 30-94 hours, is not further divided. This has been a barrier for the specialization of each operator, and lead to the loss of automation opportunities. To improve the productivity, this work aims to propose a methodology of mixed model production to revolutionize the current assembly system.

According to customer demands, auto-riveting stage have been identified as the CCR (Capacity Constraint Resource) in the system. Scheduling panel assemblies through the multiple auto-riveters has been defined as a parallel machine problem, and one new dispatching technique has been developed to minimize waiting time of the post auto-riveting processes in our previous work (Briggs et al. 2012). This paper will focus on the design of mixed production system at the panel assembly stage prior to the auto-riveting stage.

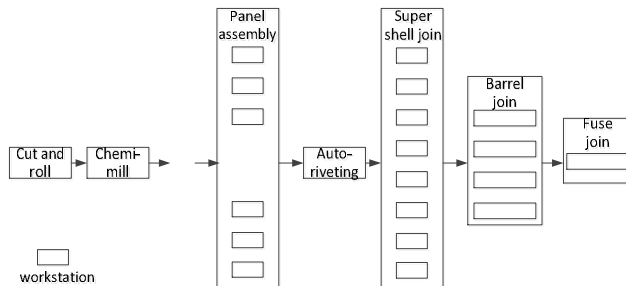


Figure1: Schematic diagram of production line of aircraft fuselages

3 METHODOLOGY AND VALIDATION

3.1 Work Content Analysis

The panel assembly processes are defined by method engineers and recorded in the Engineering Process Reports (EPR), which consists of 50-70 pages of texts for each panel. Shop-floor operators are following the instructions of EPR for assembling the aircraft panels. To estimate processing times, operations are classified into a number of categories, and standard time associated with each standard operation is predicted by using MOST (Maynard Operation Sequence Technique) through a knowledge based system (Jin et al. 2009). As these standard operations are too granular to be used for precedence analysis, five typical types of operations are defined after a thorough analysis of the panel

assembly processes as: Locate and Drill (LD, represented in green in the precedence diagram), Window Coaming (WC, in Grey), Dismantle and De-burr (DD, in Orange), Wet Assembly and Hilite Installation (WH, in Red), and Manual Riveting (MR, in White). After reviewing all the EPRs of all 16 panels and collecting all the time data for around 60,000 standard operations, the precedence diagrams are also drawn with task elements associated with their processing times, as shown in Fig. 2 Note that the normalized processing times have been used.

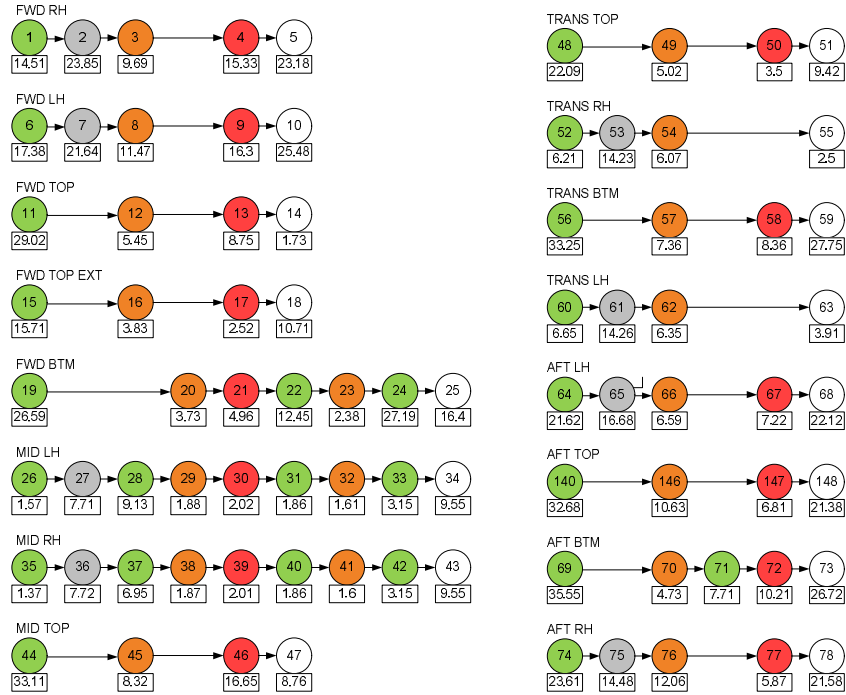


Figure 2: Precedence diagrams of aircraft panel assemblies

Note that the adjacent operations of the same type have been summed up and some closely relevant operations have been combined together to simply the precedence. Based on these precedence diagrams of the 16 panels, one joint precedence diagram is developed to show all possible process routings as shown in Fig. 3. It is observed that the dominant process flow is formed by Locate&Drill, Dismantal & Deburr, and Manual Rivet, because all panels need to pass through these operations sequentially. To have a better picture on the weight of each route, the processing times associated with each operation category for each panel is summarized in Table 1. It is clearly shown that 50% of panels (8 panels) will need the Window Coaming operation. Locate& Drill Operations will be needed at five locations in the precedence, but only for a small number of panels for the L&D except the beginning one. D&D operations are required by only three panels associated with five hours processing time in total.

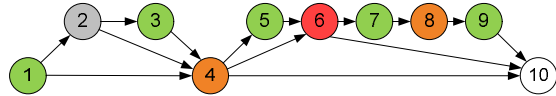


Figure 3: Joint precedence diagram of a set of 16 panels of the fuselage

3.2 Capacity Requirement Analysis and Workstation Layout Design

With the precedence diagrams obtained, the next step is to conduct the capacity requirement analysis. In the herein question, customers demand to produce five sets of panel assemblies in eight weeks (1400 hours). In order to meet the demand, the number of workstations n_j for the j^{th} machine is determined by the following equation.

$$n_j = \frac{\sum_{k=1}^{10} \sum_{i=1}^{16} t_{i,j}^k}{t_A} \quad (1)$$

where $t_{i,j}^k$ represents the process time of the i^{th} job on the j^{th} machine (category of operation) for the k^{th} fuselage, and t_A the total available time (1400 hours in this case). As a result, the capacity requirements of each machine are listed out in Table 2. Based on the joint precedence diagram and the demanded capacity, the workstation layout is designed as shown in Fig. 4. It can be observed that the mixed model production system consists of three parallel machines of LD, two parallel machines of MR, a flow system over up to five different type of machines, as well as reentrant to the LD machine.

Table 1: Breakdown of processing times (in hrs) at the respective category for each panel

Product/Work Group	Locate & Drill	Window Coaming	Locate & Drill	Dismantle & Deburr	Locate & Drill	Wet Assemble	Locate & Drill	Dismantle & Deburr	Locate & Drill	Manual Rivet	Total
FWD RH	14.51	23.85		9.69		15.33				23.18	86.56
FWD LH	17.38	21.64		11.47		16.3				25.48	92.27
FWD TOP	29.02			5.45		8.75				1.73	44.95
FWD TOP EXT	15.71			3.83		2.52				10.71	32.77
FWD BTM	26.59			3.73		4.96	12.45	2.38	27.19	16.4	93.7
MID LH	1.57	7.71	9.13	1.88		2.02	1.86	1.61	3.15	9.55	38.48
MID RH	1.37	7.72	6.95	1.87		2.01	1.86	1.6	3.15	9.55	36.08
MID TOP	33.11			8.32		16.65				8.76	66.84
TRANS TOP	22.09			5.02		3.5				9.42	40.03
TRANS RH	6.21	14.23		6.07						2.5	29.01
TRANS BTM	33.25			7.36		8.36				27.75	76.72
TRANS LH	6.65	14.26		6.35						3.91	31.17
AFT LH	21.62	16.68		6.59		7.22				22.12	74.23
AFT TOP	32.68			10.63		6.81				21.38	71.5
AFT BTM	35.55			4.73	7.71	10.21				26.72	84.92
AFT RH	23.61	14.48		12.6		5.87				21.58	78.14
Total	320.92	120.57	16.08	105.59	7.71	110.51	16.17	5.59	33.49	240.74	977.37
Panel Routing	100%	50%	13%	100%	6%	88%	19%	19%	19%	100%	

Table 2: Capacity requirement analysis for the proposed mixed-model

WORKGROUP (machines)	LOCATE & DRILL	WINDOW COAMING	DISMANTLE & DEBURR	WET ASSEMBLE	MANUAL RIVET
WORKGROUP LOAD PER SET	394.37	120.57	111.18	110.51	240.74
CALCULATED WORKSTATION REQ	2.82	0.86	0.79	0.79	1.72
THEORETICAL MIN WORKSTATION REQ	3	1	1	1	2
EXPECTED WORKSTATION UTILIZATION	94.3%	86%	79%	79%	86%

3.3 Scheduling

This section is to design a suitable schedule to meet the CCR demand, which is defined by the due date $d_{i,j}^k$ of the list of the panel assemblies. As each panel assembly is associated with varied operations and processing times, a fixed cycle time cannot be obtained. So this production system is essentially an unpaced asynchronous line, in which workpieces should be transferred whenever the required operations are completed rather than being bound to a given time span. In order to minimize waiting time, buffers may be needed in between workstations, which will influence the schedule planning considerably. The scheduling problem in unpaced asynchronous lines has been identified as a challenging research area to be studied (Boysen et al. 2008). For the herein case, due to the extra due date constraints, the problem becomes even more complex. To solve the problem, a combined backward and forward scheduling method is proposed here. The backward scheduling is employed to find the required processing order of each panel in each station in order to the due dates. Based on the resulted order, the forward scheduling is to minimize the waiting time in the whole mixed system and guiding buffer allocations. A simulation model is built up in Delmia Quest for implementing the forward schedule. Due to the space limitation, only the results are presented here. Table 3 shows the completion time for the panel assemblies through the mixed production system within the 1400 hours time frame. It can be seen that a warm-up period is needed before the cycle time dropped to below 140hours/set, and the cycle time may vary between 114.65 to 149.40 hours/set after finishing the first two sets. The WIP level (the total number of panels in the system) in increasing over time up to 27 panels, which is a little bit high as it is more than one fuselage requirement. The station utilization rate is very high, which is close to our expectation. To reduce the system WIP, a constant WIP rule is used for controlling the panel input to the system but still with the same order. As a result, the WIP can be reduced to 16 for achieving a cycle time of around 137 hours/set, although over time is needed to produce the 10 sets, as shown in Table 5. The machine utilization is a little bit lower than the asynchronous schedule, as shown in Table 6. Both the two scheduling methods are quite close to the design expectation. The selection from the two will depend on the trade-off. Comparing to existing dedicated production system, the number of workstations is reduced from 16 to 8, and the cycle time (after the initial warm-up period) is reduced by 39% from 216 hours to 137 hours, although the variations and uncertainties have not been considered in the newly proposed mixed assembly system.

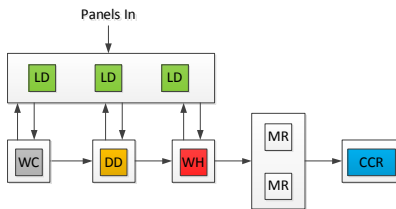


Figure 4: Workstation layout of the mixed-model production system

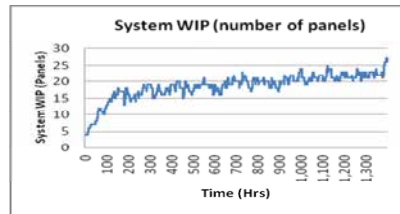


Figure 5: System WIP for asynchronous schedule

Table 3: Completion and Cycle time for each set of aircraft panels under asynchronous schedule

Set No.	1	2	3	4	5	6	7	8	9	10
Completion time (hrs)	205.56	376.16	493.69	621.82	736.77	883.42	1005.32	1154.72	1278.62	1394.28
Cycle time (hrs)	205.56	170.60	117.53	128.13	114.95	146.65	121.90	149.40	123.90	115.66

Table 4: Workstation Utilization for asynchronous schedule

LD1	LD2	LD3	WC	DD	WH	MR1	MR2
100.00	100.00	100.00	89.73	81.98	81.13	87.61	84.59

Table 5: Completion and Cycle time for each set of aircraft panels in a CONWIP system

Set No.	1	2	3	4	5	6	7	8	9
Completion time (hrs)	205.56	366.71	507.92	646.20	782.89	919.92	1057.20	1194.23	1331.51
Cycle time (hrs)	205.56	161.15	141.21	138.29	136.69	137.03	137.28	137.03	137.28

Table 6. Workstation Utilization in a CONWIP system

LD1	LD2	LD3	WC	DD	WH	MR1	MR2
95.78	94.77	96.77	85.65	78.77	78.00	82.28	84.43

4 CONCLUSION

This article presents a methodology for design a mixed production system of aircraft assembly, which appears to be the first in assembly line design considering the dependency constraints of mixed products. The methodology consists of three main stages: work content analysis, capacity requirement analysis and scheduling. The techniques for implementing the three stages are presented. The methodology is validated through a real life case study. As a result, the number of workstation is reduced by 50%, and the cycle time is also reduced by 39% comparing to the current production. The method is equally well applied to other manufacturing sectors such as heavy machinery and train carriage assemblies.

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CONFIGURATION OF ROBUST MANUFACTURING SYSTEMS

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ABSTRACT

Considering the increasing turbulence in the markets, many companies are faced with the task of responding to changes in customer demand in a flexible and timely manner. A variety of current research projects in terms of configuration of production systems deals with the increasing flexibility of several elements of a production system or the entire system, to meet the need for flexible responses. Furthermore, there is the avoidance or reduction of any kind of waste, including the creation of standards for the information and material flow processes at the heart of the company's efforts. Against this background, also organisationally robust processes are increasingly becoming the focus of operational actors. This paper points out the possibilities of influencing production systems and what characteristics exist regarding the requirement of structural changes. In this context, production control by defined loops and checking structural performance are indicators relevant to the focus of following considerations.

Keywords: robust manufacturing system, exertion of influence on manufacturing systems, manufacturing control.

1 INTRODUCTION

For several years, the trend towards increased flexibility and changeability of specific elements of factory operation can be observed. Despite the different tendencies in the modern study of production systems in terms of efficiency and adaptability allows the fundamental objectives for the production summarised as follows. It will be exclusively manufactured goods that the customer pays for. Accordingly, a customer focus within modern production systems is required. In addition, the production can be realised in the form of robust processes. In this context, it is aimed at avoiding or reduction of disorganisation. This contribution conducts an approach providing a framework for action, as the operational users recognise the need for intervention and take appropriate measures in this regard.

2 ROBUSTNESS IN THE ORGANISATIONAL CONTEXT

In this context, various influencing factors work on an existing production system. Accordingly, their impact is currently represented mainly by the effort of increased changeability. This adaptability includes an increased responsiveness to changing environmental conditions (customer demand, pricing pressures, supplier development) starting from a certain flexibility within the basic underlying structure of production. Consequently, flexibility and adaptability always contain a reactive or proactive anticipation and adaptation to the turbulence of the environment.

The focus of this paper is the optimisation of the transformation process and the avoidance of operational and organisational errors. This implies improving the process capability, increasing process linking and an increased process reliability (see Section 5.2) in terms of organisationally robust processes. Operational and organisational robustness expresses the ability of a system obtaining his functionality even under fluctuating environmental conditions. Hence, this contribution intends in particular the interaction between external environmental conditions as well as technical

and organisational aspects of production systems in the context of ensuring a reliable operation of organisational processes using a hierarchical model to analyse.

3 ASPECTS OF PRODUCTION SYSTEM DESIGN

3.1 Approaches in Planning and Design

There are two basic approaches to design and plan production systems. The classic factory planning approach enables a renewal of production systems by structural change or redesign. In this case, an analytical derivation of design criteria for the layout and overall factory is conducted by the systematic study of equipment requirements, staff, process structure, logistics requirements and dynamics of area use (Bergholz 2005 and Dombrowski, Hennesdorf and Palluk 2007). This corresponds to a majority of a renewal process in a top-down approach. Due to the lack of basic data, using factory planning methods and routines only allows to find reliable and appropriate solutions not exceeding the workplace level. Moreover, volatile environment conditions and changing requirements cause that the remaining potential cannot be exploited using this deterministic approach.

Against this background, in recent years the staff-oriented concept of lean manufacturing was gaining attention. The bottom-up approach involves the development of improvements to the layout and in particular at the level of workplace design in a participatory process. Hence, this represents an ongoing process improvement during production on the basis of an existing layout and operational organisation, without undergoing structural or organisational changes. This approach aims at extracting knowledge and experience of the employees to develop potential improvements at the workplace level.

During implementation of technical and organisational production systems arise improvements due to changing product characteristics and / or their amount (production programme) initially at the workplace level, which in turn can be exploited superficially through employee-oriented approaches such as lean management. After implementation there are unforeseeable constraints (such as qualification requirements) and changes in the product (customer demand in type and quantity) and of technological processes (new technology). Thus, adaptation needs of the production system emerge regarding organisational structure and operational organisation, investment, technical-technological aspects and personnel.

Based on incremental and continuous improvement steps, thus an adjustment of various elements of the production system at the workplace level occurs. This procedure permits an adaptation of various potential improvements through the adsorption of employee experiences (Schuh et al. 2007). On the contrary, there is the risk of path dependency (Cordes and Hülsmann 2013). In this context, the starting point for any improvements of a production system is the existing one. Consequently, there is a list of possible optimisation solutions depending of the initial situation. This creates self-reinforcing effects which in terms of improving trends can eventually lead to a dead end situation. Hence, this highlights the need for some flexibility within the search for solutions. Otherwise also the continuous improvement process has reached its limits over time and enables only a pseudo-optimisation within a limited space of action. This puts emphasis to the exigency of detecting the appropriate moment of structural changes.

3.2 Production Control as a Control Loop

In consideration of the planning of the production programme, quantitative planning, scheduling, and capacity levelling seen as elements of the PPC system, the results of the respective upstream planning level represent the input data for the next item. This is called cascaded loops (Nyhuis et al. 2009). Figure 1 illustrates a cascaded loop in production. For this purpose, the respective input and output variables of the individual viewing areas are represented and analysed in their dependency and interaction.

Based on customer demand, production orders (quantities and dates) are generated and the batch size is set. Subsequently, a selection is released from the pool of applied orders according to certain criteria and passed to the production. If the released production orders are not caused only by appointment, simultaneously a sequence is determined. This implies the definition of certain prioritisation rules. As a result, on the resource level the machine scheduling and a specific

assignment of staff deployment emerge. Depending on the existing flexibility of the production system, a capacity levelling is required. This is designed so that it enables a timely order completion (Nyhuis 2006).

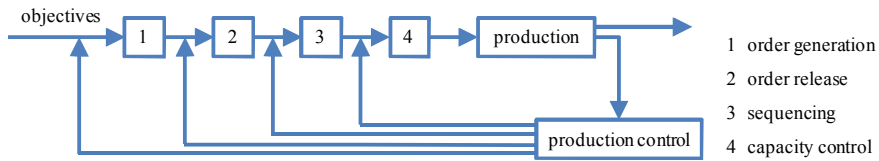


Figure 1: Cascaded closed-loop production control.

Though, unforeseen disorganisation in a production system necessarily means that its targets cannot be met. Consequently, intervention at an operational level in these cases is required to ensure compliance with deadlines. The need to control will always occur:

- when material leaves a considered production system,
- when the flow of material is divided,
- when material flows are merged and
- when the operating speed is changed (Dangelmaier and Warnecke 1997).

In this context, for the employees both informal and formal degrees of freedom apply in exercising their functions. Due to different priorities in production order acceleration in the various departments usually exists no overarching best practice. Moreover, bringing forward specific production orders always ensures that other jobs are delayed. Thereby, delayed orders risk becoming critical in respect of deadlines. Therefore, degrees of freedom as a function of the applied control method, the specific task within the production control as well as in consideration of the respective groups of people (production planners, foremen, and workers) necessitate a clear definition.

In this context, it is assumed that the formal rules of the production control in terms of their effectiveness are limited in multistage production systems. This entails other organisational rules for trapping occurring negative effects which cannot be confined by the typical production control.

4 POSSIBLE EXCERPTION OF INFLUENCE OF PRODUCTION SYSTEMS

4.1 Hierarchical Model of Interactions

A major target for influencing production systems represents, in addition to production planning, production control. Production planning produces an image of the desired target state by the generation of default values for manufacturing and assembly. Empirically, the target state will not occur due to uncertainties as well as organisational and operational disturbances. In this context, production control ensures for compliance with the desired management objectives (lead time, capacity utilisation, inventory, on-time delivery) by intervening in current production processes. Furthermore, inventory significantly determines lead time and utilisation of the production system. The adherence to schedule results from existing backlog of production orders and changes in the original sequencing in respect of a schedule-oriented order release (Lödding 2008).

In this context, the question arises: to what extent it is possible to infer from the structural point of view of production systems to necessarily organisational aspects. Furthermore, the focus is on recognising the need for changes of production systems in terms of structure (elements and resources) or organisation (organisational structure and operational organisation) and answering the question of what changes are needed within the structure of production systems (type, extent and characteristics). Against this background, figures and scope of actions are subsequently determined pertaining to the different areas and elements of the structure of production systems.

As an extension of the approach of Zülch (Zülch 1990) it is assumed that certain interactions between the various functional areas within production systems exist (Figure 2). The production

programme specifies production with a certain profile in terms of intrinsic value, timing and quantity. The temporal and quantitative profile is aimed predominantly at the customer demand and determines the production type. In this context, economic aspects are taken into account within a suitable production principle. Additionally, the resulting process principle contains both the temporal and spatial organisation of production processes. Based on the process principle, parameters can be defined for the cascading production control (Section 3.2). These parameters determine the strategic direction of the control principle (pull or push logic). Hence, the definition of the control strategy emerges.

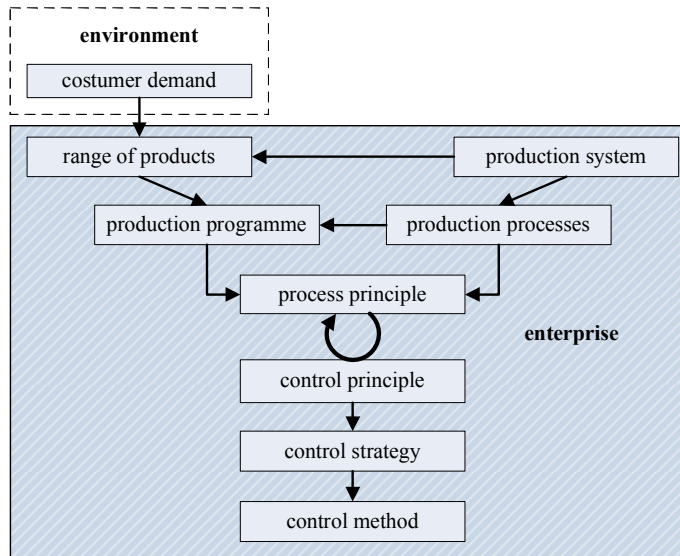


Figure 2: Interdependencies within enterprises.

In this context, the kind of order release, the sequence of production orders and the batch size are crucial parameters. The combination of these parameters enables specific control methods (e.g. kanban, load-dependent order release, etc.). Objectives, strategies and processes form obviously a hierarchical and self-similar system within production.

4.2 Combinations of Strategies

The selection of child elements is derived from existing constraints of the parent level. According to the presented task groups (Section 3.2), following strategies in the production control can be distinguished:

1. strategies for determining batch size
2. strategies for resource allocation (selection and scheduling)
3. strategies for sequencing
4. strategies for order release

In this context, a useful combination of the characteristics of the strategies is crucial. In consideration of organisationally robust processes, a limitation of the scope of action and the degree of freedom of the individual departments and process owners is required regarding sequence and priority of individual orders. This affects consequently the departmental job control in terms of self-organisation and self-optimisation (Hartmann 1995). Moreover, an establishment of a defined corridor of flexibility is necessary (see Focussed Flexibility by Terkaj et al. 2009). In this context, various

aspects of changeability, such as convertibility, reconfigurability, flexibility, adaptability and agility (Wiendahl 2002), come into consideration.

Regarding the determining of batch sizes, the batch size usually is in compliance with the amount of corresponding production orders. A change in this initial state affects the temporal organisation of production. On the one hand, splitting batches enables a simultaneous processing of a production order on different machines or workstations. On the other hand, overlap allows the transport of subsets of one batch to the next processing station without waiting for the completion of remaining partial quantities. Moreover, batches can be merged or separated at defined operations due to technical or organisational reasons (e.g. heat treatment). With respect to resource allocation, a specific scope of action usually exists in terms of timing and quantities. In consideration of an allocation of production orders to particular resources, utilisation, effort for setting-up, length of processing time or the prompt availability of the resources are crucial factors. The sequencing follows generally certain priority rules. Without intervention, production orders would pass production processes on a first-in-first-out principle. However, a number of other rules for determining the sequence are possible. These are based in turn on the set-up time, the length of processing time, the planned completion date or other priorities set by management (e.g. importance of a customer). The order release can generally be done immediately or regarding a certain date. The date of the release depends primarily on the availability of equipment and personnel capacities or backward scheduling starting from the desired delivery date of the customer.

Moreover, measures of capacity adjustment in terms of time and intensity extend the scope of action. Apart from that, both an addition to capacity and a redesign of the temporal or spatial organisation of the production processes are worth to be considered. Thus, structural changes of production systems complement appropriate strategies of configuration.

5 CHANGES IN DEMAND OF PRODUCTION SYSTEMS

5.1 Trigger of structural Changes of Production Systems

The correct determination of an appropriate moment for taking structural measures, in particular aspects of organisational structure and operational organisation, is a particularly difficult challenge. In consideration of significant structural key figures (Section 5.2) and their changes over time, basic statements about the need for structural changes arise. Furthermore, respective control limits depend on the selected scope of action considering self-optimising production units. Thus, the need of structural changes equally necessitates detecting the appropriate moment for taking corresponding measures. The proposed approach aims at establishing robust manufacturing processes and procedures by identifying the most influential factors within production systems. Basically the following trigger come in consideration: CIP (shop-floor level), strategic shift, reorganisation due to environmental requirement (state policies, technology exchange), and organisational or operational disorganisation.

5.2 Identifying an appropriate Moment

Depending on the objectives (lead time, inventory, capacity utilisation, on-time delivery), appropriate levers for influencing the production system have to be identified. First, utilisation ratio should be used as a measure of process capability. It is the quotient of processing time and lead time. Moreover, the occupancy rate is of interest. The quotient of sum of execution times and lead time is a measure of the process linkage, thus also represents the amount of work in process. In addition, this ratio expresses productivity. Lastly, processing rate is a measure of process reliability. Consequently, the ratio of sum of processing time and sum of execution times represents the stability and robustness of processes (Kletti 2007). The proposed approach includes a hierarchical model, starting from analysing the production programme to specific control methods. Within this concept holistic control variables are identified that have significant influence on the specific production system. In this context, the concepts of self-optimisation and self-similarity represent two fundamental aspects of the proposed approach (Hartmann 1995).

Furthermore, the question arises: when becomes a production system (technical and / or organizational) in its organisation (organisational structure and operational organisation) and / or structure (system elements) inefficient or even obsolete that an appropriate change is inevitable? In

addition, the kind of necessary changes (type / number / characteristics) of the production system has to be defined. For that purpose, parameters for stable and reliable production processes in terms of organisational and operational robustness have to be determined on the basis of objectives set by the management. In case of deviations and violations of the defined control limits, necessary structural changes can be differentiated as follows:

- No structural interventions (purely informational changes)
- Lightweight structural interventions (procedural changes: organisational structure, changing control parameters)
- Severe structural interventions (infrastructure-based, investment-oriented)

6 CONCLUSION

In this contribution, key levers and variables to influence production systems were identified. Furthermore, a hierarchical model is designed determining the parameters within cascade closed-loops. Based on the systematic drawn possibilities of intervention, the operational users will be in a position to act independently within coordinated control loops. In particular, this concerns the decision to exact specification of control parameters. Only the control limits are determined by management taking into account the company's goals.

The verification of this approach is in process. In this context, the concrete peculiarity of control variables considering different types of production systems will be determined. Accordingly, the questions mentioned in Section 5.2 will be answered. With respect to managerial objectives and the specific circumstances of a considered production system, interactions and interdependencies will be precisely analysed.

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IMPACT OF CLIMATE CHANGE ON FIRST GENERATION BIOFUELS PRODUCTION IN THE 21ST CENTURY

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ABSTRACT

This study assessed the potential (near, medium, and long term) impacts of climate change on first generation corn bioethanol and soybean biodiesel production in Gainesville, Florida, USA. The Decision Support System for Agrotechnology Transfer-Cropping System Model (DSSAT-CSM) was used to simulate biomass and grain yield under climate change scenarios in the 21st century with direct effect of CO₂. Weather projection was made for each scenario using the 10 year weather data for the baseline period (1981–1990). Precipitation is projected to increase by +20, +10, -10, and -20% every month throughout the growing season. Daily minimum and maximum air temperatures are projected to increase by +1.5, +3, and +5°C. Atmospheric CO₂ is projected to increase by +70 and +350_{ppm}. Simulated yields (grains/seeds and by-products) were then used as inputs into the LCA models. Results show that while bioethanol from corn and biodiesel from soybean offers some potential for GHG emissions savings per cultivated ha of set-aside land, this is tempered by rising air temperature. However, increased atmospheric levels of CO₂ relative to current condition would reduce the severe impact of warming. Only soybean biodiesel will be positively affected by climate changes.

Keywords: climate changes, biomass, biofuel

1 INTRODUCTION

Sustainability of global energy systems is an important prerequisite for sustainable development. About 81% of the world's energy demand is currently supplied by conventional fossil-based fuels such as crude oil, coal, and natural gas. However, as concern grows about the twin challenges of energy security and climate change from the burning of these fossil-based fuels, the potential for producing agricultural crop-based liquid transportation biofuels is attracting anxious interest (Sims *et al.*, 2006). Conventional bioethanol and biodiesel primarily produced from starch and edible vegetable oil respectively are the most common form of biofuels (Börjesson *et al.*, 2011). These biofuels have been shown to contribute significantly towards climate change mitigation due to reduction of combustion emissions when they are use as potential substitutes for fossil-based fuels in the transportation sector (Grau *et al.*, 2013; Renouf *et al.*, 2013). The benefits of using crop-based liquid transportation biofuels are strongly debated in recent literature and several different life cycle assessment (LCA) studies have been conducted by many researchers regarding the sustainability of agricultural crop-based biofuels in terms of energy balance and greenhouse gas (GHG) reductions.

For instance, while researchers such as Searchinger *et al.* (2008) are of the opinion that there is no benefit from production of crop-based transportation biofuels, a recent study by Gelfand *et al.* (2013) shows that crop-based biofuels from marginal lands can have positive environmental outcomes, and also according to Sims *et al.* (2006), biofuels could make a substantial proportion of future energy portfolios. However, the resulting GHG emissions reduction from these biofuels remains uncertain as there are growing concerns about how emerging global climate change will affect energy crops for biofuels production, since agricultural production of these crops tends to be more sensitive to weather and climate variables (Fischer *et al.*, 2002). LCA studies that use crop system models (CSM) coupled with LCA models to analyse the possible effects of climate change on energy crops for biofuels production have also been reported in recent literature (e.g. Persson *et al.*, 2009; Wang *et al.*, 2012). Nevertheless, most of these studies limit their research on the energy balance of biofuels grown on agricultural arable lands. Reliable projection of how climate change will affect the resulting GHG emissions savings of crop-based biofuels grown on set-aside lands would be of real benefit to policymakers for the deployment of large scale agricultural crop-based biofuels. This paper investigate the impacts that climate change will have on the GHG emissions savings of corn bioethanol and soybean biodiesel from set-aside lands in the near, medium and long-term future.

2 METHODOLOGY

The methodology is underpinned by life cycle thinking. Crop system models (CSM) and LCA models are integrated and used as tools for assessing the carbon footprint of corn bioethanol and soybean biodiesel when they are used as alternatives to conventional fossil-based gasoline and diesel respectively.

2.1 Crop models and inputs

Corn and soybean dry biomass yields (grain/seed and stover/stalk) were simulated for current (baseline) and projected climate change scenarios and used as inputs into the LCA analyses. Process based crop model simulations were run with the CERES-Maize (Ritchie *et al.*, 1998) and CROPGRO-Soybean (Jones *et al.*, 2003) of the DSSAT-CSM model v4.0.2 Software (Hoogenboom *et al.*, 2003) for corn (*Zea mays L.*) and soybean (*Glycine max*) respectively. The models simulates physiological crop responses on a daily basis as a function of climate factors (daily maximum and minimum temperature, precipitation, and solar radiation), soils, and crop management practices (cultivar, planting date, row spacing, plant population, and planting depth). The models have been applied extensively in many different parts of the world for climate change applications (e.g. Gungula *et al.*, 2003; Rötter *et al.*, 2012). Gainesville, Florida, USA, meteorological weather station data were used in the study because of readily available and reliable data in a suitable format required by the DSSAT-CSM model.

2.2 Baseline climate data and climate change scenarios

Historical ten – year daily observed climate data from 1981 to 1990 for the station were used in this study. Farm level management practices with most optimal yield were chosen for the corn cultivar, McCurdy 84aa and soybean cultivar, PIO332. Simulations were run under rain fed conditions. Table 1 depicts the climate variables used in the generation of the climate change scenarios. Here we used the “environmental modification” section of the XBuild module in DSSAT-CSM model to generate climate change scenarios using variable combinations of temperature, precipitation, and atmospheric CO₂ levels. Daily changes in the climate variables were applied to the observed daily climate records. Projections were made throughout the crops growing season.

Table 1: Climate change parameters range and values used to create climate change scenarios.

Climate Parameters	Values
Daily maximum temperature	+1.5, +3.0 and +5.0°C
Daily minimum temperature	+1.5, +3.0 and +5.0°C
Precipitation	+20, +10, -10 and -20%
Atmospheric carbon dioxide (CO ₂) concentration	+70 and +350ppm.

2.3 LCA analysis: GHG emissions calculation

The GHG $\text{kg CO}_2\text{-eq. ha}^{-1} \text{ yr}^{-1}$ for CO_2 , N_2O and CH_4 emissions were calculated using a life cycle assessment approach. This methodology was used to analyse and compare the Carbon Footprint of bioethanol produced from corn and biodiesel produced from soybean with petroleum based fossil fuels – petrol (gasoline) and diesel respectively according to ISO 14044 standard (ISO, 2006). This method advocates the system boundary expansion method – “displacement method” or “substitution method” for LCAs (Börjesson *et al.*, 2011) (Figure 1). Models were developed using the GaBi v4.4. The crop yields are based on simulated model outputs from the DSSAT-CSM model and were used as inputs for the LCA models. In this study, average energy crop yields over 10 years were taken to smooth out annual variations due to temperature and precipitation differences. The LCA steps are described in the subsequent sections.

2.4 System boundary and functional unit

The system boundary in this study as shown in Figure 1 included energy crop (feedstock) production and transportation, biofuels processing, and biofuels distribution to service station. Direct land use was also included in the study (Searchinger *et al.*, 2008). Upstream activities such as manufacturing of equipments/machines and chemicals were taken into account. The average 100 km feedstock transportation data was considered in the study (González-García *et al.*, 2010). The functional unit is 1 ha of cultivated land. All annual GHG emissions savings $\text{kg CO}_2\text{-eq.}$ are calculated per ha.

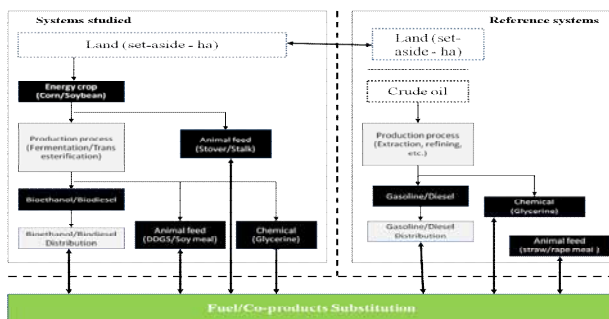


Figure 1: System description/system boundaries of bioethanol from corn (CBE) and biodiesel from soybean (SBD) displacing fossil-based fuels

2.4.1 Life cycle inventory (LCI)

The model representation of the physical processes inventory for bioethanol and biodiesel are constructed in GaBi v4.4 LCA software using ecoinvent v2.0 database unit process raw data that has been incorporated into the Software. The datasets were preferentially selected from the USA (based in the USA) which represents the study site. However, limited availability of data has always been one of the critical issues in LCA studies, where data is not available, data from RER (based in Europe) and the CH (Europe specific) were used in the analysis.

2.4.2 Life cycle impact assessment (LCIA)

The cumulative impact assessment results from ecoinvent (LCIA) for GHG global warming potential (GWP) were taken by applying the CML2001, 100 years Global Warming Potential (GWP) methodology (Renó *et al.*, 2011) due to its relevance to current legislative goals (IPCC, 2007). Our analysis accounts for the GHG emissions from energy crops cultivation (farm operations), biofuel conversion process, and distribution to regional storage (equation 1).

$$GHG_{\text{biofuel}} = GHG_{\text{farm}} + GHG_{\text{process}} + GHG_{\text{distribution}} \quad (1)$$

2.4.3 GHG emissions reduction due to fossil fuels replacement

GHG emissions reduction (GHG emissions savings) from fossil gasoline and diesel displacement due to use of corn bioethanol and soybean biodiesel respectively were calculated as the difference between emissions from the production, distribution and combustion (use) of fossil gasoline/diesel and the crop cultivation, production and distribution of bioethanol/biodiesel (equation 2).

$$GHG_{\text{baseline}} = (GHG_{\text{fossilprod}} + GHG_{\text{fossildist}} + GHG_{\text{fossilcomb}}) - (GHG_{\text{biofuel}}) \quad (2)$$

Where $GHG_{\text{fossilprod}}$, $GHG_{\text{fossildist}}$ and $GHG_{\text{fossilcomb}}$ are the fossil-derived GHG emissions from fossil fuels production (including extraction of crude oil), fossil fuel extraction and combustion of the displaced fossil fuel equivalent ($f_{\text{fossil, equiv}}$), which is the amount (kg) of the displaced fossil reference system defined as:

$$f_{\text{fossil, equiv}} = \text{biofuel}_{\text{produced}} \times S_p \quad (3)$$

Where $\text{biofuel}_{\text{produced}}$ is the amount of biofuel produced per ha, and S_p is the substitution ratio between the biofuel and the conventional fossil fuel (equation 4).

$$S_p = \frac{CV_{\text{biofuel}}}{CV_{\text{fossil fuel}}} \quad (4)$$

Where CV_{biofuel} is the calorific value of the biofuel produced (MJ/kg), and $CV_{\text{fossil fuel}}$ is the calorific value of the displaced fossil reference system (MJ/kg).

3 RESULTS AND DISCUSSIONS

Models calculations show that production of CBE and SBD per ha substituting for equivalent quantity of fossil-based reference fossil-based fuels would result in potential GHG emissions savings of -4743.32 kg CO₂-eq. ha⁻¹ yr⁻¹ and -2655.41kg CO₂-eq. ha⁻¹ yr⁻¹ respectively in the current – baseline scenario. Our result for CBE, agree well with that of Gelfand *et al.* (2013) and Larson (2006) who reported GHG emissions savings capacity of -4290 and about -4900 kg CO₂-eq. ha⁻¹ yr⁻¹ respectively from corn-based bioethanol. Similarly, for SBD GHG emissions savings potential for the baseline results corresponds with that of Larson (2006) who reported about -2100 kg CO₂-eq. ha⁻¹ yr⁻¹. For projected climate change scenarios which include a combinations of increased surface air temperatures, changes in seasonal distribution of precipitation, and elevated atmospheric CO₂ concentration, the potential impacts of these changes are complex, and include not implications for energy corn and soybean dry biomass yields per ha, but also the biofuels produced and the resulting potential GHG emissions savings that could be achieved. This demonstrates that climate change will have serious implications not only the agronomy of these crops, but also and their Carbon Footprint.

As depicted in Figure 2, for the near (+1.5°C temperatures increase), medium (+3°C temperature increase), and long term (+5°C temperature increase) we can expect GHG emission savings to decrease between 9 to 46% for CBE in all the scenarios assessed compared to the baseline scenario. The overwhelming trend of the impacts of all projected climate change scenarios on CBE was negative, the more the temperature increases the more the GHG emissions savings per ha declines. However, the magnitude of the impacts varied with scenario. The impact of precipitation change on GHG emissions savings from CBE is less noticeable compared to SBD. A rise in atmospheric CO₂ concentration to 680 ppm (+350 ppm) would lead to a CO₂ fertilization effect on the corn thereby raising plant yield and potential GHG emissions savings per ha. With respect to the dynamic of change in GHG emissions savings for CBE between +70 and +350 ppm CO₂ gains in GHG emissions savings due to CO₂ enrichment are going to rise by 10%.

Also as shown in Figure 3, GHG emissions savings for SBD are predicted to decline for all climate change scenarios with +70 ppm CO₂ concentration. However, under double CO₂ concentration (+350 ppm) GHG emissions savings are predicted to increase higher than the baseline condition in some scenarios probably due to CO₂ fertilization effect which tends to reduce the impacts of increased temperature and decreased precipitation. The direct beneficial effect of atmospheric CO₂ enrichment offset the GHG emissions savings decrease in some of the scenarios considered. For instance, at +1.5°C temperature increase coupled with a 20% increase in precipitation and +350 ppm CO₂ increase in GHG emissions savings higher than the baseline scenario is predicted (+27%).

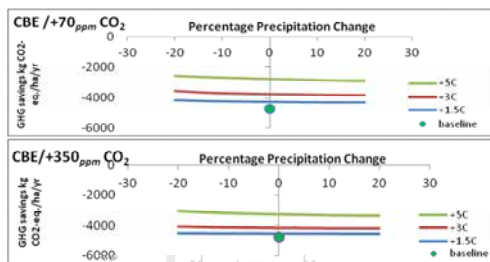


Figure 2: Impact of climate variables on GHG emissions savings of Corn bioethanol (CBE) under current (baseline) scenario and different climate change scenarios by the end of 21st century at different atmospheric levels of CO₂.

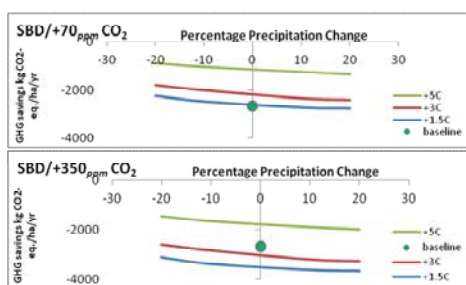


Figure 3: Impact of climate variables on GHG emissions savings of Soybean biodiesel (SBD) under current (baseline) scenario and different climate change scenarios by the end of 21st century at different atmospheric levels of CO₂.

With respect to the dynamic of change in GHG emissions savings for SBD between +70 and +350 ppm CO₂ gains in GHG emissions savings due to CO₂ enrichment are going to rise by 23%. In contrast, as the climate gets warmer in the long term future (+5°C temperature increased), the GHG emissions savings for SBD are projected to decline in all climate change scenarios even under doubled CO₂ (+350 ppm) enrichment. For instance, at +5°C temperature increase, and 20% precipitation decrease, there is substantial declines in the GHG emissions savings (-46%). This demonstrated that SBD production would be equally well if not better, in a warmer (milder temperatures increase) and CO₂ enriched future. This might not be unconnected with the photosynthetic advantage that that soybean (a typical C3 crop) has over corn (a typical C4 crop) at considerably high temperatures and elevated atmospheric CO₂ than today's condition (Oliver *et al.*, 2009).

4 CONCLUSION

The impact of climate change on the life cycle GHG savings of CBE and SBD were undertaken using LCA methodology. The approach relies on LCA models in combination with CSM models. GHG savings per ha per annum varies from feedstock types and climate change scenarios. CBE can generate GHG emissions savings of -4743.32 kg CO₂-eq. per ha per annum and SBD can generate -2655.41 kg CO₂-eq. per ha⁻¹ yr⁻¹. Therefore, bioethanol from corn and biodiesel from soybean grown on marginal lands could present very good opportunities for reduced GHG emissions when compared with fossil-based fuels. However, these would be affected by changes in future climate. CBE would suffer serious decline in the net GHG emissions savings per ha per year in all the near, mid, and long term future. While SBD would also be negatively affected by climate change in some scenarios, and under double CO₂ concentration (+350 ppm) and at temperatures lower than +5°C coupled with increased precipitation, the net GHG emissions savings are predicted to increase higher than that of

the baseline condition probably due to CO₂ fertilization effect. A temperature rise of +5°C will have a devastating effect for both CBE and SBD even with doubled CO₂ concentration. Climate change will affects energy crops production differently. Care must therefore, be taken by farmers, policy makers, and all stake holders in chosen which crop to grow and under which condition in the future.

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Quality & Performance Measurement

FACTORS INFLUENCES ISO 9000 IMPLEMENTATION IN SAUDI MANUFACTURING INDUSTRY

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ABSTRACT

This paper reports the preliminary findings for a PhD study. A review of literature found a lack of empirical research on factors that affect the implementation of ISO 9000 (a family of quality management standards) in Saudi Arabia. This research attempts to fill the gaps in existing literature. The main purpose of this work is to provide empirical data on the most common factors that influence the implementation of ISO 9000 in the manufacturing sector in Saudi Arabia. In order to achieve this aim, a three-stage industrial survey has been carried out using an adequate sample of data to investigate potential factors. The result of the findings from this survey revealed that ISO 9000 is more popular in medium and large organisations in Saudi Arabia. In light of this finding, top management support may be one of the most important factors influencing the implementation of ISO9000 in the manufacturing industry. This is followed by the adequacy of human resources and rigour of internal audit.

Keywords: ISO 9000, Manufacturing, Saudi Arabia, Influences factors.

1 INTRODUCTION

The ISO 9000 standards are related to management quality systems and are meant to assist businesses to meet the desires of consumers and stakeholders. (Poksinska, et al, 2002). The standards are published by the International Organisation for Standardization (ISO), and support organisations to follow specific and well-documented techniques in production or services. These techniques explain how functions should be performed (Singels et al., 2001). ISO 9000 has been applied throughout the United States of America (USA), Europe, and in other parts of the world. It has become a subject of interest in various developing nations, such as Saudi Arabia. Saudi Arabia is one of the three nations in the Middle East that hold ISO certification alongside the United Arab Emirates (UAE) and Egypt, (ISO survey, 2008). The number of organisations that adopted ISO 9000 in Saudi Arabia was 876 compared with 3283 organisations in the UAE. The number in Saudi Arabia is lower because there were not many firms involved in international marketing. Since then, Saudi Arabia has experienced rapid growth in its economy and in international marketing activities so that the number of ISO 9000 certification is increasing. The Economist Intelligence Unit, (1998) described the economy of Saudi Arabia as "Relatively more prosperous than that of a typical Third World economy since the country is the largest producer and exporter of oil in the world". In 1997, the Gross National Product (GDP) of

Saudi Arabia was the largest in the Middle East, followed by Israel, Iran, Egypt, UAE, Algeria, Morocco, and Kuwait respectively, and was one of a few countries in the world that saw rapid economic growth. Despite the publications and research available into ISO 9000, there is limited literature focused on discussing the difficulties and problems related to ISO 9000 and even less on its adoption and implementation in the Arabic countries (Al-mijrab, 2010). While the implementation of ISO 9000 in different nations has been investigated, every country has its own different environments and issues; hence this empirical research will be based on the issues specifically related to the manufacturing sector of Saudi Arabia.

2 LITERATURE REVIEW

Empirical evidence reveals that the implementation of ISO 9000 is associated with many obstacles, which is a common experience shared by organisations throughout the world (Gader et al., 2009; Mersha, 2007; Lipovatz et al., 1999). The literature shows that most of the failures result from a lack of commitment from top management, employee resistance to change, lack of knowledge and understanding of the ISO requirements, insufficient training and quality knowledge, a low level of quality awareness and culture, the allocation of personal responsibilities and constraints on resources such as manpower, time and finance. Another study by Sampoio, Saraiva and Rodrigues (2009), suggests that the reasons for major difficulties implementing ISO 9000 are as follows; low level involvement of top management and employees, poor information flow (for the functioning of the quality system), resistance to new responsibilities, lack of appropriate technical knowledge, and difficulty in communicating new tasks and functions for each job. Matts. C and Dan. C, (1996) identified some of the factors for successful implementation of ISO 9000 in the Swedish industry, the top three were; management commitment, involvement and commitment of all personnel concern and work performed using mainly their own resources.

Zeng et al. (2007), highlighted the problems in implementing the ISO standards in China, citing the following problems; lack of commitment from some certifying bodies, excessive competition between certifying bodies, and the desire of certifying bodies to offer a total package of services from consultation to certification. In addition, the present study by Hesham (2010), based on the manufacturing sector in Egypt recommended 11 possible factors that affect the implementation of ISO 9000 and asked members to rank the level to which each aspect has assisted the interviewed companies the most. The ranking ranged from “very helpful” to “not helpful at all”. By examining the results, it was clear that the most beneficial factors in successful implementation of ISO 9001:2000 are commitment from senior management; the firm’s internal auditor; a well-structured system of procedures; and assistance from the parent company or partner.

Another study completed in Kuwait by Aldowaisan & Youssef (2006) indicated that the training, availability of resources, improved documentation system, sufficient time, and implementation framework were the common factors affecting ISO 9000 implementation. As can be seen from the review, there are some common factors affecting implementation of ISO 9000 that are universally applicable in both developed and developing countries. Ibrahim (2005) mentioned in his research that European organisations encountered similar problems of organisational culture, lack of understanding of ISO 9000 standards, and lack of human resources as common barriers in the ISO 9000 certification process. In addition, there are common factors that affect different geographical regions, and the research conducted in the Arab countries found that they faced similar issues; organisational culture, top management commitment, lack of human resources, government impact, and lack of understanding of the ISO 9000 standards.

3 METHODOLOGY

The main purpose of this part of the PhD study is to provide empirical data on the common factors that influence the implementation of ISO 9000 in the manufacturing sector in Saudi Arabia. In order to measure this, the first task is to compile an acceptable list of applicable factors, secondly, to test the effect of these factors, and finally to uncover some of the missing details. Therefore, a three-stage survey was carried out using appropriate samples to investigate the factors affecting the implementation of ISO 9000 in the manufacturing industry in Saudi Arabia. The three-stage approach is as follows:

- 1) An initial questionnaire was sent to participants to confirm whether the selected common factors are applicable to the Saudi manufacturing industry.
- 2) A second questionnaire focused on finding the main hypotheses such as factors that may affect the implementation of the ISO standards and techniques to analyse the data.
- 3) The last stage uses a face-to-face or telephone interview.

The purpose of the first stage was to triangulate data, compare the factors collected from the literature, to come up with a triangulation and a list of factors. From the results of this part of the survey, a new list of factors was suggested to the companies using an “agree or disagree” type of questionnaire. This type of questionnaire is appropriate for investigating whether the most common 15 factors affecting the implementation of ISO 9000 applies to the Saudi industry or not. These 15 factors are listed below:

- | | |
|---|--|
| 1. Top management commitment | 9. Insufficient knowledge in quality programme |
| 2. Employee resistance | 10. Ignorance of ISO importance |
| 3. Difficulty of performing internal audits | 11. Weak inter-departmental relations |
| 4. Absence of consulting boards | 12. Unwillingness to change work systems |
| 5. ISO 9000 requirements are unrealistic | 13. Inflating the size of documents |
| 6. Shortage of financial resources | 14. Unwillingness to change organisational culture |
| 7. Insufficient human resources | 15. Absence of quality guidelines |
| 8. Insufficient employee training | |

To be able to differentiate the degree of agreement and in order to discuss and analyse the results a five-point scale was used (5: strongly agree, 4: Agree, 3: Neutral, 2: Disagree and 1: Strongly Disagree). Once the list of the appropriate factors was compiled, the second questionnaire focused on hypothesis and multi regression questions to find out the effect of these factors. The last stage was to rank the relative importance of these factors, which was achieved by using a multi criteria decision-making approach (as there is a subjective element and people attribute differently to the factors). It was appropriate to use the Analytic Hierarchy Process (AHP).

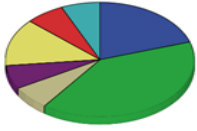
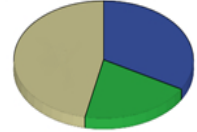
4 THE ANALYTIC HIERARCHY PROCESS

The AHP is an organised strategy for working with complicated choices. Rather than recommending a "correct" choice, the AHP helps the decision makers find the one that best matches their needs. The AHP provides an extensive and logical structure for constructing a choice issue, for comprising and quantifying its components, for relating those components to overall objectives, and for analysing alternative solutions. It is used around the world in a wide range of choice circumstances, in areas such as education, business, and government (Saaty, 2008).

5 RESULTS OF ANALYSIS

This study only forms part of the research, and the initial results from the first stage are presented here. The first questionnaire was issued to 100 manufacturing companies in Saudi Arabia by E-mail. Initial responses have been received and more are expected, to date, only 15% of the questionnaires have been returned, as shown in Table 1.

Table 1: Company details

Question	Result
1) What is the sector of your company?	<p>the company's sector</p>  <ul style="list-style-type: none"> chemical Engineering Extraction Food Other Pharmaceutical Textile
2) What is the average number of employees in your organisation?	<p>the number of employees</p>  <ul style="list-style-type: none"> 50-100 100-200 200-300 300-500 more than 500
3) What is the type of ownership in your business?	<p>type of ownership of the company</p>  <ul style="list-style-type: none"> Mixed government & Privat Private Joint venture with foreign company
4) How long have you operated in Saudi Arabia?	<p>period of your organizations operating in Saudi Arabia</p>  <ul style="list-style-type: none"> 3-10 Years 10-20 Years Above 20
5) How long has your company been registered for ISO 9000 standards?	<p>registration to the ISO 9000 standards</p>  <ul style="list-style-type: none"> Less than a year 1-3 years 4-10 years More than 10 years

From the initial responses, it was found that 40% of the organisations are in the engineering sector and more than 46% had more than 500 employees, which indicates that ISO 9000 is more popular in medium and large organisations. 46.7% of companies operating for more than 20 years have held the ISO 9000 standard for more than 10 years. Of the companies who responded to the survey, 40% are joint ventures with foreign companies and 33.3% are mixed government and private sector, indicating that the Saudi private sector is still struggling with the implementation of ISO 9000. Respondents also declared that commitment from senior management had most impact on the success of the implementation of ISO 9000, describing this as a critical factor, as shown in Table 2. The second most important factor was said to be insufficient human resources and the difficulty of performing internal audits, which was ranked third in importance of all factors, followed by insufficient employee training. One factor of less significance in the implementation of ISO 9000 is the shortage of financial resources.

Table 2: Factors influencing the implementation of ISO 9000 in the Saudi manufacturing industry

Rank	Factors	N	Mean	Std. Deviation
1	Top management commitment	15	4.53	.743
2	Insufficient human resources	15	3.9333	1.38701
3	Difficulty in performing internal audits	15	3.87	1.506
4	Insufficient employee training	14	3.7857	1.42389
5	Insufficient knowledge of quality programme	15	3.7333	1.43759
6	Ignorance of ISO importance	15	3.6667	1.34519
7	Absence of quality guidelines	15	3.4000	1.40408
8	Shortage of financial resources	15	3.2667	1.09978
9	Unwillingness to change organisational culture	15	3.2000	1.42428
10	Weak inter-departmental relations	15	3.1333	1.68466
11	Unwillingness to change work system	15	2.8667	1.45733
12	ISO 9000 requirements are unrealistic	15	2.7333	1.33452
13	Employee resistance	15	2.4667	1.12546
14	Inflating size of documents	15	2.4667	1.24595
15	Absence of consulting boards	15	2.4000	1.18322
	Valid N (list wise)	14		

Notes: The mean score was based on participants' level of agreement from a choice of five. 5 = strongly agree, 4=Agree, 3= Neutral, 2= Disagree and 1= Strongly Disagree.

The factor considered the most important, was commitment from senior managers, which is supported by the findings of other researchers (Hesham. M, 2010, Matts. C, Dan. C, 1996). The study found that insufficient human resources and a lack of qualified internal auditors who are able to support organisations to comply with ISO 9000 requirements are essential factors to successful implementation of ISO 9000. In respect of human resources, this can be affected by other factors such as inadequate levels of education, misinterpretation of the standards, low worker morale, and high worker turnover (Sabah M., 2011).

6 CONCLUSION AND FUTURE WORK

The literature review clearly shows that there are different factors affecting implementation, which vary from country to country, and are influenced by environment and culture. The most common 15 factors have been identified, reviewed, and presented to the manufacturing industry in Saudi Arabia in an attempt to triangulate the extracted data with data obtained from the field. The findings of this study indicate that the commitment and support of top management was regarded as the most important factor in implementing ISO 9000 in the Saudi manufacturing industry, which is a factor affecting most organisations in Saudi Arabia and in other parts of the world. Insufficient human resources and difficulty performing internal audits are also found to be important factors, and are similar to other findings that existed in the literature. This research may be valuable to the companies that are engaged in the Saudi manufacturing industry that are desperate to get the qualifications, and can learn from the findings of this study. Future work will be carried out to prepare and issue the second questionnaire, which focuses on hypothesis and multi regression questions in order to find the effects of implementation factors. This will be followed by interviews with organisations to rank the relative importance of these factors.

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APPLYING PERFORMANCE MEASURES TO SUPPORT INFORMED DECISION MAKING AT AN OPERATIONAL LEVEL

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ABSTRACT

Performance Measurement Systems (PMS) have commonly been applied to evaluate and reward performances at managerial levels, especially in the context of supply chain management. However, evidence suggests that the effective use of PMS can also positively influence the behaviour and improve performance at an operational level. The purpose of the study described in this paper is to develop a conceptual framework that adopts performance measures for *ex-ante* decision-making at an operational level within the supply chain. A case study at Coca-Cola Enterprises has been carried out and as a result, a conceptual framework of the PMS has been developed.

Keywords: Performance measures, Performance Measurement System, supply chain, decision-making, flexibility.

1 INTRODUCTION

Research in the field of Performance Measurement Systems (PMS) has drawn on a multitude of disciplines, from production and operations management to accounting and management control. Even though the use of PMS is common amongst managers for decision-making during the review periods and when defining and evaluating the success of strategic goals (Gomes et al., 2011), the equivalent cannot be said for the use of the same systems as *ex-ante*¹ support tools to drive performance (Grafton et al., 2010). Furthermore, although research suggests that PMS can positively influence individuals at an operational level, there is little evidence that it has been put in practice. As a consequence, individuals require the right information, at the right time, in the right format and at the right cost, and meeting these requirements remains a challenge (Schuff et al., 2010).

Performance measurement innovation benefits organisations through the delivery of strategically aligned metrics that facilitate decision-making. Providing decision support frameworks and tools that integrate multiple measures in the evaluation process may reinforce the importance of these measures and thus enhance their efficacy in relation to strategic goals (Franco-Santos, 2012). Recent research also suggests organisations have to be flexible so as to adapt to frequent changes in customer demand especially in fast moving industries (Poon et al., 2011). To do so, adjustments to production have to be considered within short time periods and as a consequence operational level employees are being empowered to make more decisions and take subsequent actions.

¹ Ex-ante means that a decision results in an outcome, as opposed to making a decision based on the outcome of an action.

From the literature and observation it has been found that decision-making processes tend to either be based on expert knowledge and little accurate data, or alternatively made by IT systems (e.g. decision support systems), using complex algorithms that provide employees with the answers (Chapman and Kihn, 2009). The main limitation in the former is that individuals are not making informed decisions and in the latter, psychological empowerment is being confined, consequentially tending towards reduced motivation and capacity to solve problems.

Taking these factors into consideration, the purpose of the study in this paper is to increase supply chain flexibility by enabling individuals at an operational level to respond to variations in customer demand, whilst considering the overall impact on the supply chain. A framework has been co-developed with Coca-Cola Enterprises (CCE) enables the informed ex-ante decision-making, by utilising performance measurement as drivers in the decision-making process at an operational level within the supply chains. The framework was then validated at the CCE Sidcup manufacturing facility focusing on the Production Planning Department.

2 DATA COLLECTION AND ANALYSIS

The wide variety and high capacity within CCE Sidcup made it an ideal location to carry out this study. Demand is customer driven, originating at the direct consumer or supermarket chains, which is communicated on a weekly basis to the manufacturing sites, by the head office. An evermore-fluctuating demand in products has resulted in a need to develop flexibility mechanisms (including lean tools), in order to rapidly respond and maintain a competitive edge. The data to develop the framework were therefore collected using a combination of interview, questionnaire and probing.

Interviews were conducted with five individuals with a combined experience of 107 years. These were middle and top level managers with expertise in various food industries, aerospace and information technologies. The semi-structured interviews and the use of mind-maps helped to identify the strengths of PMS and extract concrete examples of the issues faced in a supply chain to achieve greater flexibility and decision-making efficacy.

The interviews covered the details of the supply chain, perceived triggers, influencing factors, root causes, standard operating procedures (if applicable), the PM in place (if applicable), the importance and impact of decision making across the supply chain, and the relevance of developing a structured approach at an operational level. The findings obtained from these examples were then used in developing various models and the process framework, with direct applicability to the operational level of a fast moving consumer goods supply chain.

To further understand the degree of PM misalignment a questionnaire was developed and attempted by 30 individuals at all levels of the sponsoring company. The questionnaire was devised with the support of high-level managers to identify the key PM applicable to the CCE supply chain. A six point Likert scale was applied, whereby one is the most important and six the least. The questionnaire was completed by 30 employees at CCE Sidcup site, ranging from shop floor technicians and office workers, to middle and top managers. The reasoning behind the answers provided was captured and then manually recorded.

The results obtained from the data collected indicated that depending on the hierarchic level and role within the organisation, employees had different views as to the PM priorities and the general organisational alignment. Each of the six top and middle level indicated that the PM were all of high importance as they were all present in their pre-established yearly targets. Results also indicated that they perceived PM to be aligned throughout the site, which was further supported by their reasoning. In contrast, at a non-management level, from the 24 individuals in five different departments, the priorities of the PM varied depending on the department.

Following the interview and questionnaire, a detailed investigation was carried out at the Planning Department. Roles and responsibilities, information systems, activities and respective processes, and other resources available were all considered. This was achieved by following employees' actions, analysing existing company documentation, in addition to interviews and workshops. Once a general understanding of the Planning Department was reached, the decision-making process of a production change request was documented. Subsequently gaps in the process were identified, and a brainstorming session was then carried out to understand how to fill the gaps.

As there was no clear PM for the Planning Department, a set of inherent measures was recorded and, with the support of the current and previous managers responsible for the department, a selection of the most significant was obtained. This information, alongside the decision-making evidence, was used to add and extract details from the concept. It also formed the basis for the development of the tools which allow for prioritising and displaying data. The main gaps were found to be the lack of use of data and clear targets when making decisions. In addition, an established procedure for decision-making did not exist and this opened up an opportunity for the development of the concept.

3 FRAMEWORK DEVELOPMENT

The concept has been developed in several iterations with inputs from both theory and practice. It aims to close the existing gaps, through the use of PM, which should ultimately increase flexibility across the supply chain. In contrast with the existing performance measure systems, this concept takes the first step towards using PM as drivers. In addition, the concept integrates an illustration of how PM can be aligned throughout the supply chain, whilst incorporating the use of existing strategic level PMS. The business scorecard is given as an example.

The conceptual model has been developed with reference to a guiding equation below, in addition to strategic and tactical factors at CCE.



Figure 1: Graphic representation of the model equation

The model is strengthened with a process framework and set of tools that aim to provide a graphical representation of how flexibility at an operational level can be achieved in practice. Decision-making at an operational level is triggered by two main sources: manufacturing performance or customer driven. In both cases, the optimum decision is the one that creates the smallest impact, and highest throughput, to the supply chain. However, decisions are commonly made in an ad hoc manner, based on personal experience. The risk here is that individuals use emotion rather than information (Gunasekaran and Kobu, 2007). The use of PM in decision-making is therefore twofold. It drives the supply chain towards common accepted goals, and provides the data required to make informed decisions. As can be seen in the pyramid-like models (Figures 2 and 3), the concept proposes an organisational structure of a supply chain model and suggests how to align the PM in order to achieve common goals. The actual process of decision-making is illustrated in the form of a process framework (Figure 4).

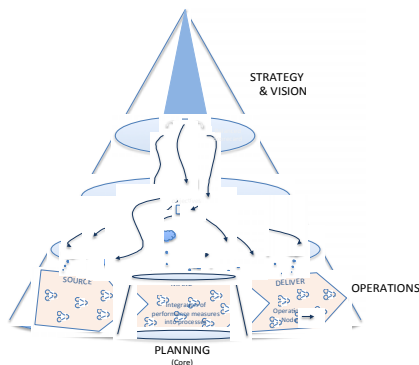


Figure 2: Adapted Model of the Supply chain

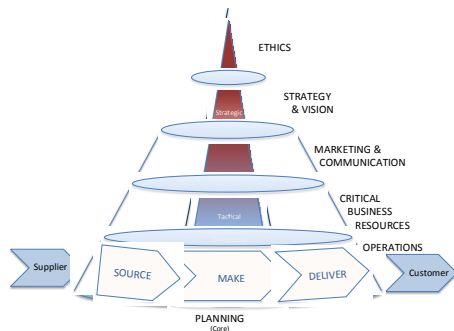


Figure 3: Illustration of organisational PM alignment

4 TESTING AND VALIDATION

Testing the concept and its content demonstrated how the developed decision-making process and the supporting tools can be applied in a practical context. The examples all come from the Planning Department and the PM alignment is identical in all cases. The main scorecard objectives (strategic level) were linked to the related PM (operational level) as illustrated in Figure 3. Due to confidentiality, details have purposely been omitted. The PM were then integrated into the production change decision-making process and production change requests applied.

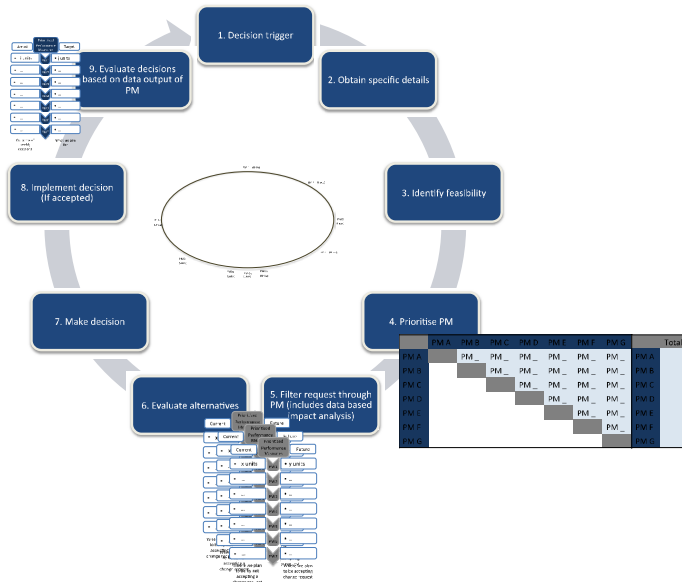


Figure 4: Decision making process and supporting tools

When analysing the three examples, the first brought to light is that the tool and the expert planners reached the same conclusion, however the tool provided an objective set of data to support the decision. In the second example, the decision-making process applied by the researcher allowed this analysis to be carried out, as opposed to ad-hoc reasoning. This enabled the identification of the simulated option with the least impact to the organisation. In the final example, the decision-making process framework was able to use the performance measure related quantitative data to conclude that the most beneficial decision for the organisation would have been to maintain the plan, rather than cut production. Therefore, by testing the tool, its power in providing data to make informed decisions has become evident.

The concept was validated in five iterations. Following each iteration, expert academics, after the first and fourth iteration, or industrialists, in the remaining iterations, validated it. The first validation was after the 'industry expert data collection', in the form of two semi-structured interviews. The second validation took place half way through the in-house case study, to verify the gaps identified in the ad-hoc decision-making process and corroborate the propositions that emerged from the thinking session. The following validation was after the specific PM for the Planning Department had been extracted and applied to the concept models and framework. A validation interview permitted the concept to be tested with examples from the Planning Department. The fourth validation semi-structured interview focused on approving the complete developed concept with academia, whilst the fifth validation was industrial based, taking the form of a questionnaire. The results were based on a 5-point Likert scale, ranging from 'strongly agree' to 'strongly disagree'.

5 DISCUSSION

It was a conscious choice to base the research project on a single case study. As the objective was to develop a solid concept, it was preferred to focus on one case only and to recommend that future research validate the concept in other areas of the fast moving consumer goods supply chain across different organisations. The in-depth, single case study allowed the complexities of decision-making and PMS in a highly-rated, market leading fast moving consumer goods supply chain to be understood. However, the limitation to this approach is that the concept needs to be further tested in similar environments.

Academic researchers and industry experts alike have established that organisational flexibility is paramount for organisations to maintain competitive in today's market (Tang and Tomlin, 2007). Researchers have suggested that in order to achieve organisational flexibility, PM need to incorporate flexibility measures (Beamon, 1999). However, this research suggests that rather than solely incorporating the flexibility measures, the use of PM as drivers to guide decision-making is what may lead to a more effective organisational flexibility. The guiding model developed in collaboration with CCE (Figure 1) is simple enough to be accessible to those who may require it, although at this stage it has not yet demonstrated qualitative results.

Following academic recommendations to develop an integrated PMS that supports an integrated supply chain (Gunasekaran and Kobu, 2007), a concept of a PMS that drives informed decision-making at an operational level has been created. This research project has considered what is known as one of the most significant paradigm shifts of modern business management; that individual organisations in a fast moving environment must do business as supply chains, so as to maintain competitiveness (Lambert and Cooper, 2000). It has also considered that the success of strategy fulfilment is highly dependent on the degree of alignment of PM, and that highlighting supply chain objectives and goals allows for associating targets at all levels (Akyuz and Erkan, 2010). This has often failed to occur in previous PMS (Holmberg, 2000). Furthermore, at the operational level the different sections of the supply chain perform different activities. Some activities involve decision-making in the process. It is at this level that the aligned PM should be integrated.

The analyses of the findings have led to inferences that have been incorporated into the framework. They include; within a fast moving consumer goods supply chain, flexibility involves producing according to customer demand, which encompasses being agile to short-term requests. This ultimately increases supply chain resilience (Tang and Tomlin, 2007). To accommodate short-term requests the supply chain has to be able to make decisions not only at a strategic level, but also at a tactical and operational level. At an operational level, the department that makes decisions with a significant level of impact to the CCE Sidcup site is the Production Planning Department. Short-term decision-making at an operational level implies making daily choices. Some are in-house driven, due to material availability and unplanned downtime; CCE Head Office, driven by customer demand, originates other requests. By proving that the process enables employees to make informed decisions, the acceptance of the change request can no longer be an ad hoc decision.

It is acknowledged that complex decision-making environments involve a greater degree of uncertainty (McDaniels, et al., 1999). However, it is fundamental that individuals have adequate information and expert knowledge, as well as the required materials, to make choices (Kiker et al., 2005). For a fast moving consumer goods industry, adequate information implies the data is accurate and as up-to-date as possible (ideally real time). Studies have also shown that too many restrictions in decision-making activities tend to have negative effects (Berglund and Karlton, 2007). Provided flexible information technology tools are available and there are processes in place at an operational level, it is possible to optimise the decision-making process.

The decision-making process has been developed taking the previous factors into consideration. Financial and non-financial performance measures appropriate for production planning at CCE Sidcup site were contemplated in the testing phase. The framework has been developed to allow these measures to vary across the site and between organisations. This allows for the concept to be agile as it can suit different areas of a supply chain. There is, however, a risk that the individual making the analyses of the PM priorities may not have the required skills. Thus, it is important to provide the necessary training and institute clear roles and responsibilities.

6 CONCLUSION

The concept proposed in this research project draws on the existing literature as well as the case study. It presents the resulting framework for decision-making at an operational level, which is intended to increase supply chain flexibility with regards to customer demand. The formation is put forward as a concept for making informed decisions in a timely and accurate manner, applying PMS an innovative way. It is expected that the concept provides a ground to build tools that practitioners can employ to gain a competitive advantage, by satisfying fluctuating customer demand whilst quantitatively considering the impact on the supply chain. The concept responds to several key issues in the current research in PM. Firstly, by commissioning organisational routines as one of its constructs, it provides a solid organisational foundation that are lacking in the PM literature. Furthermore, by contemplating an alignment of PM with organisational strategy, the concept is balanced in every direction, be it strategic determinants, tactic performance criteria or on a metrics level. The testing and validation of the concept has considered it useful and valid as a concept.

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**PERFORMANCE MEASUREMENT SYSTEMS AND METRICS:
A FRAMEWORK FOR MONITORING OIL OPERATIONS**

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ABSTRACT

Oil operations involve high levels of capital equipment and high capacity production processes for which performance measures can assist with monitoring production throughout the oil industry stages. The approach taken in this paper is to utilise the lifecycle approach of asset management as well as organisational resource factors in an integrative manner. This research will examine the use of performance measurement in both private and public oil companies with a focus on Developing Countries. National Oil companies are of national economic importance in Developing Countries.

Thus purpose of this paper is to develop a conceptual framework for performance measures of current and future oil operations and the associated asset management for field operations. The approach taken is to recognise the national context and strategic drivers and then to examine within this context the three areas of: Asset Management; Oil Operations (including Technology and Development; Management approaches; Partnerships) and Performance Outcomes.

Keywords: Performance Measurement, Performance Management, Asset Management.

1 INTRODUCTION

Kincaid (1994) signifies that to conduct correct appraisals and develop tactics for progression, performance management is highly important. According to Lebas (1995) performance management execution is highly important when the definition of improving performance is concerned as it helps in making strategies for decision making and focuses on a better future as well. Performance Measurement or better known as PM is continually been realised as a key mechanism regarding performance management considering it offers and incorporates the entire related information significant whilst undertaking decisions linked to the undertaking of handling a firm's performance Bititci et al. (1997).

The recent works collected on performance management by different researchers such as Flapper et al. (1996) and Bititci et al. (2005) have shown the growth from defining universal commendations on cultivating performance to articulating performance measurement (PM) structures and schemes as identified by Folan and Browne (2005), lastly towards the problems of executing as well as expending performance management systems to achieve optimal performance in the organisation.

This research aims to examine the changing drivers of oil operations in developing countries and their strategic importance and the associated evolution of operational performance and metrics for National Oil Companies (NOCs). Therefore the purpose of this paper is to develop a conceptual framework for performance measures of current and future oil operations and the associated asset management for field operations.

2 BACKGROUND TO PERFORMANCE MEASUREMENT AND MANAGEMENT

According to different researchers such as Keegan et al. (1989), Kaplan and Norton (1992) and Neely (1998) the field of performance management has been very important when identifying performance

management and its structures. Azzone et al. (1991) and Dumond (1994) identified the different applicable performance measures stating that the researches done in the past regarding performance management were different as it was expected that they would be performing feedback functions by giving the organisation important data regarding the firms business model. In today's time the researches conducted are different as they use the importance of performance management to measure the success of learning and innovation in an organisation and the level of applicability derived Kerssens-van Drongelen (1999). Furthermore performance measuring signifies the pointers of performance that could be implemented when making distinctions both internally or externally in an organisation Ho et al. (2000) considering they are a good identifier or comparison.

Performance measures can describe the performance purposes in a strong and calculable way Hitchcock (2002) and O'Sullivan et al. (2004). Key performance indicators (KPIs) were identified according to five chief standpoints; physical features of the project, funding and promotion, improvement and learning stakeholders, and project procedure Yuan et al. (2009). They also mention when the major KPIs are recognised, confirmed, and examined after that a sincere performance measurement will be possible. It was argued that credentials of key performance indicators and the implementation of performance measurement of focus on assessment and overall performance toward an organisation's mission Cable and Davis (2004). Consequently the resolution to adopt performance measurement underlies in the comprehension of the influences of the decision-making done by the management and its attainment and disaster in recommending conceivable enhancements Cable and Davis (2004).

3 CONCEPTUAL FRAMEWORK CONCEPTUAL

When discussing performance indicators, there are factors influencing the nature of both public and private organisations in content to their facilities. These performance indicators are essential when identifying the evaluation of facilities for the coordination of the organisations goals and missions with its performance and hence help organisations to easily identify and manage their goals Cable and Davis (2004) and Cripps (1998).

3.1 Creating Value in Oil and Gas

The oil and gas sector is creating value by linking various factors in the oil industry, starting from the resource base to production, processing, transportation, and finally to the market. Resource base is nature's gift, however, transforming this into reserves and production needs investment and effort. The production link in the value chain is connected to field recovery factors and production costs, both of which have technical and managerial dimensions and the same for the processing and transport stages of the chain Stevens (2008). Most of the time the market value of oil (crude or petroleum products) and gas is assumed to be outside the control of National oil companies (NOCs). Generally NOCs are operating with control over costs and efficiency, therefore they directly create value.

3.2 Performance Measurement and Analysis

Hoque and James (2000) argue that about a resiliently constructive relationship amongst performance measurement processes and their financial enactment as a result of the study conducted by them regarding the implementation of non-financial processes maintained by contexts such as the BSC. Perera et al. (1997) however signified that there is a negative association amongst using non-financial measures and financial performance. Furthermore, Ittner et al. (2003) also studied the same idea which related to the practice of measurement association methods like those of the BSC and hence signified that there was no connexion amid these techniques of BSC and economic performance. Henceforth, Franco-Santos (2007) identifies the association amid using the non-financial methods in decision-making rewards as well as the financial enactment of the firm therefore reporting that although the association existed, it wasn't applicable by being negative. Type of users have highly influence on the selection of performance measures, different users as managers, supervisors and customers need different measures for different purposes Lebas (1995).

3.3 Proposed Framework for Monitoring Oil Operations

The approach taken is to recognise the national context and strategic drivers and then to examine within this context the three areas of: Asset management; Oil operations (including technology and development; management approaches; partnerships) and Performance outcomes.

Figure 1 represents a conceptual model based on the extant literature which will underpin this research. The model comprises two parts: firstly asset management and its effect on oil operations. Mitchell and Carlson (2001) described the term asset management as “a tactical, cohesive set of ample procedures (financial, management, engineering, operating and maintenance) to gain greatest lifetime effectiveness, utilisation and return from physical assets (production and operating equipment and structures)”. When talking about physical asset management it can be seen that in the process industry this predominantly fixated on maintenance management models Amadi-Echendu (2004). Secondly oil operations and their factors affecting the performance of NOCs. Table 1 summarizes the key literature that includes theoretical and empirical support of the second part of the framework.

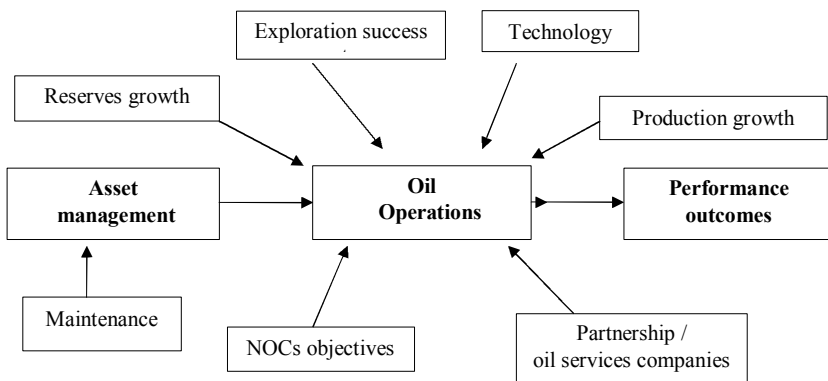


Figure 1: Proposed conceptual research model .

Table 1: Literature map of the research framework concerning oil operations.

Performance metrics	Cite
NOCs objectives	Mommer (2002) , Boué (2003), Victor (2007), PESD (2006), Energy policy (2009),CEE (2007) and Stevens (2008).
Production growth	Stevens (2008), CEE (2007), Energy policy (2009) and Victor (2007).
Reserves growth	Stevens (2008), CEE (2007), Energy policy (2009) and Victor (2007).
Exploration success rate	CEE (2007), Stevens (2008) and Energy policy (2009).
Technology	Stevens (2008), CEE (2007), Al-Naimi (2004), Zanoan (2002), Alleyne (1980), PESD (2006) and Energy policy (2009).
Partnership	Stevens (2008) and PESD (2006).

4 STUDY DESIGN

A large number of studies were designed to undertake the assessment of effect of performance management inventiveness on the real performance of a firm but many studies conducted in recent times have controversial results to this statement Neely (2005). Several of these for instance are presenting the constructive influence of the BSC on performance. The approach for this study will be a cross functional questionnaire survey within oil companies to identify current practices and their impact on performance management. The intention is to interview key personal's with expertise in oil operations primarily NOCs in Middle East.

National Oil Companies are firms that were initiated after the 1950's by the government for the public sector. National oil companies (NOCs) are highly important as they control the oil reserves that

supply the entire world's necessity for liquefied fuel. Furthermore In various countries around the world the most important sector on which the economy depends is the oil sector and is considered vital for economic development Stevens (2008).

National oil companies (NOCs) dominate almost 77% of the worlds extracted oil reserves which account to more than eleven hundred billion barrels. These excavated resources are within the control of the NOCs without any participation by the IOCs. Furthermore the foreign international oil companies now have control over less than ten per cent of these oil reserves Jaffe (2007). In terms of oil reserves, 9 out of the top 10 international companies are NOCs, and with respect to natural gas reserves, all the top ten global companies are NOCs .These NOCs are principally resident in developing countries. Also In terms of world oil production NOCs are in the top 20 oil producing companies in the world Jaffe (2007).

In addition to the hydrocarbons sector, NOCs have an impact on most of the energy services such as electric supply as they are often seen as states within a state because they are large suppliers of state revenues and are commonly in the top of the most attractive firms for employees in the country.

Although many IOCs claim their abilities of supplying technology, capital and access to markets, many governments have not allowed them to access the hydrocarbon resources therefore, NOCs have often found it difficult of involving in partnerships with outside firms in addition, most of the NOCs find it more difficult to operate outside their home market. In terms of utilising the reserves IOCs demonstrate that their efficiency is higher than NOCs,International Oil companies are better at least 33% more than NOC's when shifting oil reserves into utilisable output Victor (2007).

4 CONCLUSION

It is significant to understand the national oil companies performance in order to know their role and impact on energy sector. This work is aimed at developing a research framework that understands the impact of Asset management and operations on firm's performance. At this early stage of the research, our work lacks the validation of tools and the data required to draw conclusions on such relationships, which will be the succeeding phase of this research. At the current stage, we look forward to receiving criticism and feedback that will help us improve our understanding on how to best achieve this research's aims.

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CONSTRAINED BAYESIAN INFERENCE OF PROJECT PERFORMANCE MODELS

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ABSTRACT

Project performance models play an important role in the management of project success. When used for monitoring projects, they can offer predictive ability such as indications of possible delivery problems. Approaches for monitoring project performance relies on available project information including restrictions imposed on the project, particularly the constraints of cost, quality, scope and time. We study in this paper a Bayesian inference methodology for project performance modelling in environments where information about project constraints is available and can be exploited for improved project performance. We apply the methodology to probabilistic modelling of project S-curves, a graphical representation of a project's cumulative progress. We show how the methodology could be used to improve confidence bounds on project performance predictions. We present results of a simulated process improvement project in agile setting to demonstrate our approach.

Keywords: Bayesian Inference, Project Performance Model, S-Curve, Project Constraints

1 INTRODUCTION

Project performance models play an important role in the management of project success. They provide paths to discovering what one does not know. In manufacturing, performance models are integral part of projects, e.g. process improvement projects, development projects, product-based projects and manufacturing infrastructure projects, helping companies to consistently succeed in timely delivery of quality products and services (Lim and Yeo 1995, Yang 2013). When used for monitoring project progress, project performance models offer predictive ability by providing, for example, early warning signals of possible activity-coordination and delivery problems, resource conflicts, and risk of overruns. This is especially so in projects characterized by very high, difficult to quantify, levels of uncertainty created in part by the quality and completeness of information, diversity of interests and susceptibility to external influences (Atkinson, Crawford, and Ward 2006). The quality of the models depends largely on the available project information incorporating restrictions imposed on the project.

There are established techniques for monitoring and analyzing project performance including program evaluation and review technique (PERT), the critical path method (CPM), earned value management (EVM), project management control charts, and more recently burn-up, burn down and cumulative flow charts in agile environments (Aguanno 2009, Fleming and Koffleman 2010). The approaches are primarily deterministic and draw criticisms for their failure to account for the inherent uncertainty in project planning, execution, and performance measurement. The general criticism of the deterministic approaches centres on a) their inability to account for uncertainty, b) the erroneous mathematical assumption in techniques such as PERT and CPM that in any project network there is a unique, longest (i.e. critical) path, and c) the lack of confidence bounds on predictions which are essential to effective decision making under uncertainty (Pohl and Chapman 1987). These criticisms motivate the need for probabilistic approaches and new probabilistic performance modeling methods for project monitoring such as Stochastic S-Curves (Barraza, Back, and Mata 2004), control limit curves (Barraza and Bueno 2007), and Bayesian betaS-curve (Kim and Reinschmidt 2009) have been developed. We study in this paper a Bayesian inference methodology for project performance

modelling in environments where information about project constraints is available and can be exploited for improved project performance. We use the idea of truncated distributions. Truncated distributions arise naturally in many practical situations particularly when the variable of interest falls within certain tolerance limits. To truncate a distribution is to restrict its values to an interval and re-normalize the density so that the integral over that range is 1. We apply the methodology to probabilistic modelling of project S-curves and illustrate how the methodology could be used to improve bounds on project performance predictions, using a simulated process improvement project in agile setting.

We introduce project S-Curves in Section 2. In Section 3 we present our Bayesian approach and this is followed in Section 4 by an illustration of the approach using a simulated process improvement project in agile setting. We end the paper in Section 5 with concluding remarks and future research directions.

2 PROJECT S-CURVES

A project S-Curve is a graphical representation of the cumulative progress of a project from start to finish, with the horizontal and vertical axes showing time and cumulative project effort/progress respectively. The term derives from S-like shape of the curve, flatter at the beginning and end and steeper in the middle - a universal characteristic of all projects, regardless of the type, size, and complexity of a project. Since all projects are unique, the individual shapes for various projects vary according to the nature of the projects. Different methods can be used at different stages of a project to infer project S-curves.

At the initial stages, with only sketchy project definition, the general approach is to use empirical methods to derive baseline S-curves using historical data acquired from previous projects. As the project progresses and project-specific information becomes available, target S-curves based upon actual data can be developed for use in monitoring the project and refining target performance levels. Analysis of S-Curve permits a quick identification of project growth, slippage, and potential problems that could adversely impact the project if corrective action is not taken (Figure 1). Several alternative deterministic methods of inferring S-curves have been studied along with various mathematical

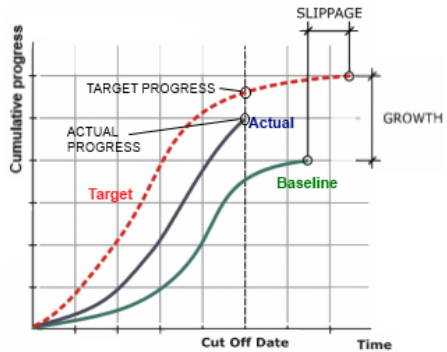


Figure 1: A Project S-Curve

formulas for generalizing cumulative project progress as a function of time e.g. Miskawi (1989), Murmis (1997) and Cioffi (2005). Deterministic inferences of project s-curves can be inadequate because projects are often subject to the influence of many factors and executes in uncertain environments. In contrast to deterministic approaches, researchers have suggested the use of probabilistic frameworks for project performance modelling using S-Curves. As an alternative to using deterministic S curves and traditional forecasting methods, Barraza, Back, and Mata (2004) introduced stochastic S curves (SS curves) to determine forecasted project estimates. Simulation is used to generate stochastic S-curves based on defined variability in duration and cost of the individual activities within the process. Stochastic S curves provide probability distributions for the budget and time values required to complete the project at every selected point of intermediate completion. Barraza and Bueno (2007) introduced an implementation of performance control limit curves for both actual cost and elapsed time, obtained using Stochastic S curves. Kim and Reinschmidt (2009) developed Bayesian BetaS-curve method (BBM) for schedule performance control and risk management of on-going projects. The BBM uses Bayesian principles and beta distribution in a probabilistic forecasting framework to drive continuous monitoring of project performance by revising beliefs about target project S-curve based on additional observations obtained during the project. The BBM is known to provide, early in the project, much more accurate forecasts than the earned value method or the earned schedule method and as accurate forecasts as the critical path

method without analyzing activity-level technical data. An advantage of the beta distribution is its ability in extensive distributions of forms only with two shape parameters. The probability density function (PDF) of the generalized beta distribution defined on the interval $[A, B]$ with shape parameters α and β is given by:

$$f(x) = \frac{1}{B(\alpha, \beta)} \frac{(x-A)^{\alpha-1} (B-x)^{\beta-1}}{(B-A)^{\alpha+\beta-1}} \quad A \leq x \leq B; A < B < \infty; \alpha, \beta > 0 \quad (1)$$

where $B(\alpha, \beta)$ is the Beta function defined by:

$$B(\alpha, \beta) = \int_0^1 t^{\alpha-1} (1-t)^{\beta-1} dt \quad (2)$$

The case where $A = 0$ and $B = 1$ is called the standard beta distribution. The formula for the cumulative distribution function (CDF) of the beta distribution, also called the incomplete beta function ratio, is defined by:

$$F(x) = \frac{\int_0^x t^{\alpha-1} (1-t)^{\beta-1} dt}{B(\alpha, \beta)} \quad (3)$$

$$= \frac{B(x|\alpha, \beta)}{B(\alpha, \beta)}$$

The BetaS-curve function is defined as follows.

$$\text{BetaS-Curve}(x|\alpha, m) = \frac{B(x; T|\alpha, \beta)}{B(\alpha, \beta)} \quad (4)$$

where m is the location of the mode and T is project duration. The shape parameters are restricted to $\alpha, \beta \geq 1$ in order to confine the plausible solution space to S-curves with unimodal PDF.

Bayesian paradigm can be applied from the onset of a project by integrating prior performance information (e.g. the prior probabilistic estimates of project duration and costs) with observations of new actual performance to arrive at posterior performance information. Bayesian inference offers a formal method to combine evidence external to a project, represented by a prior probability curve, with the evidence generated during the execution of the project, represented by a likelihood function. The attractiveness of Bayesian methods has also grown due to the availability of powerful MCMC simulation methods that provide the technology for sampling the posterior distribution of parameters and there are now more efficient techniques for handling constraints (Gelfand, Smith, and Lee 1992, Chen, Shao, and Ibrahim 2000).

3 BAYESIAN S-CURVES WITH PARAMETER CONSTRAINTS

In the Bayesian approach, we assume there is an S-Curve model S in a space $\mathfrak{S}$ of possible S-Curves and that S fits our project. S is parameterised by a set of random variables θ that establish the geometric properties of the curve. In this paper, following Kim and Reinschmidt (2009), we specify S using a beta distribution and focus on three parameters - the shape parameters $\alpha, \beta \geq 1$, and a duration parameter T . The location of the mode m can be derived from α and β . Bayesian inference concerns the estimation of the values of the unknown model parameters about which there may be some prior beliefs. These prior beliefs can be expressed as a probability density function $f(\theta) = f(\alpha) f(\beta) f(T)$, assuming the parameters are chosen independently, and may be interpreted as the probability placed on all possible parameter values before collecting any project-specific data. We assume constraints C are specified a-priori on the parameters. C truncates the prior distributions, restricting the domain of the probability distribution and allowing the parameters to only take permissible values. For example, for the random variable T , $T_L \leq T \leq T_U$ places lower T_L and upper T_U bounds on project duration. The PDF of T over the interval $[T_L, T_U]$, is given by:

$$f(T) = \begin{cases} \frac{g(T)}{G(T_T) - G(T_L)}, & \text{if } T_L \leq T \leq T_T \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

where $g(\bullet)$ and $G(\bullet)$ are the PDF and CDF of the unconstrained distribution. Suppose we model T using a normal distribution $N(\mu, \sigma^2)$, then let the constrained duration parameter T_c be a truncated Normal $TN(\mu, \sigma^2, T_L, T_T)$ random variable. The probability density function of T_c over interval $[T_L, T_T]$ is given by:

$$f(T) = \begin{cases} \frac{\frac{1}{\sqrt{2\pi\sigma^2}} e^{-(T-\mu)^2/2\sigma^2}}{\Phi\left(\frac{T_T-\mu}{\sigma}\right) - \Phi\left(\frac{T_L-\mu}{\sigma}\right)}, & \text{if } T_L \leq T \leq T_T \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

where Φ is the standard normal CDF. As the project progresses, we capture project-specific data $D = (d_1, d_2, \dots, d_n)$ whose elements d_i consists of cumulative progress data w_i at time step t_i . We use the information to revise our prior beliefs. The dependence of observations D on the parameters θ can be expressed as the likelihood function, $f(D|\theta)$. $f(D|\theta)$ is calculated as the product of the likelihood of each observation. We make the deviations between actual times of performance reporting and the planned times determined by our model $S(w_i|\theta)$ to be normally distributed with zero mean and standard deviation σ . That is,

$$\begin{aligned} f(D|\theta) &= \prod_{i=1}^n f(w_i, t_i|\theta) \\ &= \prod_{i=1}^n \frac{1}{\sqrt{2\pi\sigma^2}} \exp[-0.5((t_i - S(w_i|\theta))/\sigma)^2] \end{aligned} \quad (7)$$

The likelihood function is used to update the prior beliefs on θ to account for the new data. This updating is performed in the constrained space θ_c using Bayes theorem which can be expressed:

$$f(\theta|D) = \frac{f(D|\theta)f(\theta)}{\int_{\theta_c} f(D|\theta)f(\theta) d\theta} \quad (8)$$

where $f(\theta|D)$ is called the posterior distribution and expresses the probability of the parameter values after observing the new data. Once the posterior distribution is available, any features of θ , such as the marginal distributions or means and variances of the individual parameters, as well as the predictive distribution of future observations, require integrating over the posterior distribution. For example, the marginal posterior distribution of an individual parameter e.g. T can be calculated as

$$f(T|D) = \int_{\theta_c, -T} f(\theta|D) d\theta_{c, -T} \quad (9)$$

using Gibbs Sampling (Gelfand, Smith, and Lee 1992). $\theta_{c, -T}$ represents all the parameters except T .

4 ILLUSTRATION

We illustrate the Bayesian approach using a simulated process improvement project in agile setting. For our purpose we focus on requirements evolution in a project whose dynamics is illustrated in Figure 2. The duration of the example project is between 42 and 55 time steps.

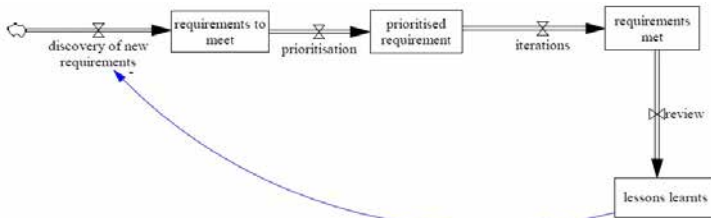


Figure 2: System Dynamics of the Project

Table 1: List of Simulation Parameters and their Settings

Parameter	Description	Setting
baseReqs:	Set of requirements initially specified to be met	Uniform (20,30)
discoveredReqsOrd:	Set of requirements routinely discovered	Uniform (10, 25)
	Arrival rate of the discovered requirements	Poisson (1.4)
discoveredReqsLearn:	Set of requirements discovered through learning	$0.4 \times \text{baseReqs} \times \exp(3.0)$
	Acceptance probability of the discovered	Uniform (0.6,1)
valueReqs:	Value of requirement	Uniform (100, 200)
	Volatility of requirements value	Normal $\mu = 0$ $\sigma = 0.15 \times \text{valueReqs}$
effortReq:	Effort/Cost required to deliver a requirement	Uniform (10, 100)
PrioritisationStrategy:	Requirements are prioritized according to highest value first	

The process improvement project is initiated with a base set of requirements. A requirement is an ordered pair (cost, value). The requirement values are volatile and non-negative. As the project progresses new requirements are discovered and added to a prioritized list of requirements to meet. The project is executed iteratively. In each iteration, a requirement is selected from the prioritized requirements list and processed. When the selected requirement is fulfilled, a lessons-learnt review is conducted and work moves to the next iteration. New requirements may be discovered routinely and may also emerge as a result of the lessons-learnt review. The discovered requirements are added to the requirements list at the start of a new iteration. The execution process continues in cycles until all the requirements are fulfilled. The simulation run ends when all the requirements are fulfilled. To control how the simulation runs, we set the parameters of the simulation to values listed in Table 1.

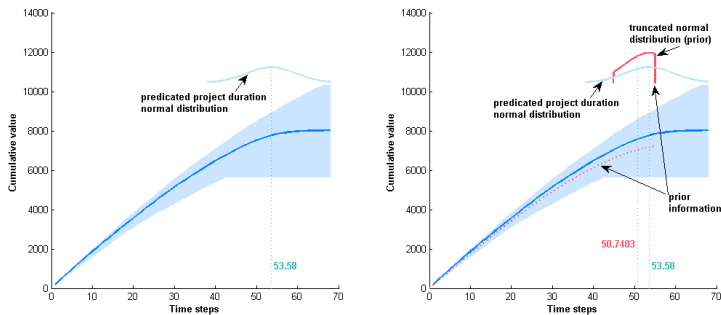


Figure 3: Predicted Performance – a) obtained from simulation and b) the prior information.

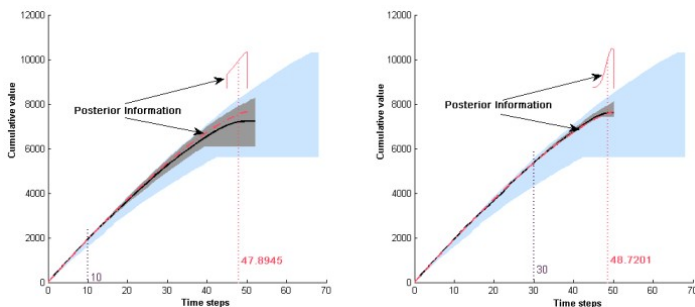


Figure 4: Predicted Project Performance at intermediate points – a) 10 time steps and b) 30 time steps.

The results of the simulation are averaged over 1000 runs. Figure 3a shows the predicted project duration obtained from simulation. The predicted duration is normally distributed with mean 53.58 and standard deviation of 6.04. Figure 3b shows the predicted normal distribution truncated to 45 and 55 time steps, below and above respectively. We use the truncated normal distribution alongside a Beta (1.01, 1.32) as prior information (Figure 3b). The posterior distributions for actual project data at time steps 10 and 30 are shown in Figures 4a and 4b respectively. The truncated distributions provide improve confidence bound on project duration and the resulting models respond quickly to early project reports.

5 CONCLUSIONS AND FUTURE WORK

The focus in this paper has been on Bayesian inference for project performance modelling in environments where information about project constraints is available and can be exploited for improved project performance. We adopted the idea of truncated distributions and use a simulated process improvement project in agile setting to illustrate the approach. Projects constraints were assumed to be valid and known a-priori. Capturing the project constraint information and accounting for uncertainty in the constraints as part of the Bayesian framework are some areas of future work.

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A STUDY INTO CONTINUOUS IMPROVEMENT INITIATIVE SUSTAINABILITY

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ABSTRACT

The idea of continuous improvement is familiar to most managers and there are many examples of how its use can increase a company's overall performance. However, while numerous companies have adopted the approach, very few have seen the long term sustainability of such programmes. This paper reports on research that was carried out into the sustainability of continuous improvement initiatives. A case study was carried out in a manufacturing company that had been using the approach for five years. The case study identified several factors that helped to sustain the initiative but it also revealed some elements that had a negative impact.

Keywords: Continuous Improvement, Sustainability, Performance Improvement,

1 INTRODUCTION

The advanced manufacturing tools employed for improving operational performance are well known (Anand et al., 2009). One of these is continuous improvement (CI) which is the planned and systemic process of ongoing incremental and company-wide change of existing practices aimed at improving performance (Boer et al, 2000). Research into the implementation of CI programmes suggests several enabling factors such as management commitment and training (Rapp and Eklund, 2002). What is less well understood are the practices employed to sustain CI performance improvement gains (Bateman, 2005). A previous study of continuous improvement initiatives found that only 11% of the companies that had introduced them considered them to be successful (Anand et al., 2009).

There have been a few studies undertaken to help better understand this area of change management. Based on their research Bessant et al. (2001) proposed a behavioural model which suggested that the development and sustaining of CI capability is an evolutionary process that sees the organization move through 5 stages, leading to the "learning organization".

However, is the development of a CI capability only achievable through the attainment of the predetermined levels of behaviour development in the sequence observed by Bessant et al. (2001)? An alternative theory, proposed by Van de Ven and Poole (1995), is that of a constructive mode of change; that is one that consists of changes based on goals as the final cause for guiding change. This often produces unpredictable solutions, albeit they are made within a consistent set of broad organizational values. In theory, this would allow a more spontaneous or self-directed approach, with different routes to developing a CI capability. Consequently, this approach may not be consistent with the model of this development process proposed by Bessant et al. (2001).

A different approach to CI capability development is that by Anand et al. (2009). They found that infrastructure practices can fulfil an important role via the coordination and support of projects and create a culture for continuous improvement to help sustain an initiative beyond the immediate gains.

It has been suggested that for CI initiatives to be successful, there needs to be: support and priorities at a strategic level, employee participation and commitment and a set of tools and processes to facilitate the company approach (Bessant et al, 1993). It is also important that the employees have training in both the tools and techniques (Bessant et al, 1993; Jorgensen et al, 2007). What is not clear is whether rewards and incentive schemes are important factors for successful CI programmes (Bessant et al, 1993).

Although the research that has been carried out has improved our general understanding of how to build a CI capability, some issues, such as improving idea generation and selection, have received less attention. An examination of the CI idea generation process is needed because of the different approaches organizations have adopted for this task. Delbridge and Barton (2002) reported that “there is widespread evidence that plants are appointing specialists to lead or facilitate continuous improvement”. While, others, such as Anand et al. (2009) have emphasized that “a hallmark principle of most CI initiatives is that the best process improvement ideas reside in front-line associates”. In light of this, they suggest there is a need for further research into whether CI methods experts can act as conduits for bottom-up sustained flow of improvement ideas, thus obviating the need for additional infrastructure mechanisms to capture improvement ideas directly from front-line employees.

2 RESEARCH AIM

The aim of this exploratory research was to examine how continuous improvement initiatives are planned and executed. In particular, the research investigated the factors that helped to sustain such initiatives over several years. The research had the following research question:

What are the factors that help to sustain continuous improvement initiatives?

3. RESEARCH METHODOLOGY

The case study method was selected as the methodology to address the research questions. A leading manufacturer in the engineering sector was selected for this case research. The company was selected because it had invested significantly in the development of CI. This initiative had been sustained by the firm over several years, albeit with varying levels of success.

At the factory, semi-structured interviews were carried out with a cross section of employees, from the top of the organization right down to the shop floor. Interviews were conducted with the following individuals:

- Managing Director
- Manufacturing Manager
- 2 Manufacturing Team Leaders
- Human Resources Manager
- 7 Production Operatives

All interviews were recorded and at the same time detailed notes were taken by the interviewer. In addition to the interviews, company documents were examined. These included: manufacturing strategy, factory performance data (for example: first time pass rate, productivity), employee training information, employee absenteeism, kaizen activities and their results.

The company was willing to give the researcher copies of most of these documents but, in the case of financial statements they were not able to take copies and only allowed to inspect them and make notes.

The authors were also able to visit the shop floor and to view the factory layout and examine the data presented on the shop floor (team performance measures, CI results).

3.1 Analysis

The case analysis synthesized evidence from three sources; the interview transcripts (and notes), documentation provided by the case company, and our observations on the factory tour. The case analysis was conducted in two main stages:

- The case was reviewed separately to build a complete picture of the organization's approach to continuous improvement and its development. Triangulation was used between different respondents' comments and between their statements and company documentation
- Data reduction was then performed to 3-4 page case description. This was sent to the chief contact at the company to check the detail and also to ensure that they did not contain information that was likely to compromise their business.

4. RESEARCH RESULTS

4.1 Background

The case company is a leading engineering firm and it produces large white good items for the consumer market. Its factory is part of a large network of 10 plants. The factory has several assembly lines and also a metal press shop and a paint area.

The arrival of a new Managing Director in 2006 saw the start of significant change in the factory. He started by introducing 5S into the factory and then followed it up with training in lean manufacturing (MUDA training course – 1 day) and also Yellow Belt training. Alongside the increased training he initiated the Kaizen idea scheme (suggestion scheme). In the past five years there has also been significant investment in automation both in assembly and the paint shop. These investments have helped to reduce costs and improve quality.

The factory had over the last few years developed two ways to undertake continuous improvement, these are:

- Kaizen ideas scheme – all employees are expected to submit 2 continuous improvement ideas per year. The employees complete a form (outlining their idea), which is entered into an electronic system; these are then passed to the relevant Manufacturing Team Leader (MTL) for evaluation and approval (or rejection). If the idea is approved then the relevant steps are taken to bring the idea to fruition.
- Continuous improvement projects – these tend to be relatively large scale projects which are developed after a training course. So, for example, a group of operators who had completed a Yellow Belt course would be asked to work on an improvement project.

The results of the continuous improvement initiative, for the period 2008 to the end of 2012, can be seen in Table 1. The table shows the total number of ideas implemented, the number of ideas with cost savings and the total value of these savings.

Table 1: CI: Ideas implemented by year with costs savings

Year	2008	2009	2010	2011	2012
No of Ideas	4	61	45	60	45
No of ideas with cost savings	2	54	33	28	17
Cost savings in £1000s	50.2	424.3	126.6	50.6	24.1

4.2 Case Analysis – Emerging Factors

The analysis of the data by the three researchers identified several factors that appeared to be associated with the sustaining of the continuous improvement initiative at the case company.

Senior management focused on continuous improvement

The senior managers interviewed were focused on the continuous improvement initiative. The managing director had started the initiative and along with the previous manufacturing director had been the driving force behind it. The managing director in particular had kept an eye on the initiative and maintained the continued emphasis on it as he states “I had to push it, to keep it young”. During the morning meeting that the MD had on the factory floor with the MTLs, he would always ask about the progress of improvement projects and if anybody had ideas for improvements in the plant.

Front line employees and middle managers expected to make improvements

The strong focus on continuous improvement by the senior management team translated into an expectation that the front line employees and the middle managers should make improvements. The managing director stated that he wanted everybody to be involved in CI (“everybody should be involved in CI”, Managing Director), and this expectation was reiterated by the interviewees.

Rewards for participation

The interviews revealed that the company had linked the Kaizen idea scheme to the plant bonus system. For every idea that an employee put into the scheme they got a number of points that went towards their personal bonus. The maximum number of ideas that they would get rewarded for was 2 per year. For some of the interviewees this was a motivation to put ideas in, as one commented “you get a bonus for putting a Kaizen in, it gives you the motivation to put an idea in” (Production Operator). However, one interviewee had not put any ideas into the scheme in the past and did not intend to put any in the current year.

Employees also got points for working on or leading the improvement projects. However, two operators reported that shop floor individuals were reluctant to lead projects, considering this to be an activity that the MTLs should do. It is worth noting that the total number of ideas submitted had declined in the last two years, as can be seen in Table 1.

Focus of day-to-day activities

A few of the front line employees who were interviewed commented that the factory management was also concerned with achieving production volume targets and this had resulted in continuous improvement project work stopping, as one production line employee commented when boiler orders increase “the projects (improvement projects) get pushed to the side” (Production Operator).

Continuous improvement culture is present

The organization had tried to build a culture of continuous improvement; they had taken actions to encourage all employees to come up with ideas for improvements. The idea scheme was considered to be the vehicle to get everybody involved. The scheme had been very successful in the first few years as one operator commented “Kaizen was very successful when they first launched it, got good ideas, some good savings” (Production Operator). However, since then, the number of ideas had declined. One MTL had tried to encourage improvement by placing an ideas board on the shop floor to encourage the production operators just to write their ideas on post-it notes and put them on the board. Another MTL always ended his monthly team brief with a report “what can we do better”; he stated that he was getting anywhere up to ten ideas which he then pursued with the individuals and helped them to complete a Kaizen ideas scheme sheet.

Continuous improvement infrastructure for idea selection and processing

The case company had an infrastructure that supported CI. The ideas scheme was successful at the start but recently had been in decline. There appeared to be several reasons behind this. Firstly, the operators stated that the process took too long and when finally a decision was made, if it was negative, there was no constructive feedback as to why the idea was rejected. Secondly, the

information that was to be provided had increased, in particular since the involvement of the finance department. Operators were now expected to detail the cost savings to be made – in the past, an estimate was sufficient.

This requirement meant that more work had to be done on the idea before it could be submitted; this had alienated some operators and one MTL now had to spend time with his team members helping them to complete the Kaizen ideas form.

Improvement project leadership

The case company had tried to ensure that the individuals leading the improvement projects were trained in the use of CI tools, had the support of a trained facilitator and came from the shop floor rather than the ranks of management. However, the operators were reluctant to take on the project leadership role and most projects tended to be run by MTLs.

Standardised improvement methods

The interviews indicated that they were using a standard approach to the continuous improvement projects they worked on. A manufacturing team leader stated that they “have a CIP process which is a group standard” (Manufacturing Team Leader). Some of the techniques that the employees used during projects had come from the Yellow Belt training they had received in the last five years.

Standardisation of the improvements made

The interviews indicated that the case company had a standardised way in which improvements were incorporated into a process. The company had standard operations procedures (SOPs) for the operations in the factory; when an improvement was made the SOP would be updated. The production operators would then be trained in the new procedures and then observations and checks would be made to ensure they were being followed.

Training in continuous improvement provided

The interviews indicated that the shop floor employees received formal in-house training in continuous improvement techniques. They were encouraged to go on the training course by the awarding of points which would go towards their personal bonus. However, recently, a Yellow Belt training course was cancelled because of the increase in customer orders; during the interviews, several of the production operators questioned management priorities and their real commitment to CI.

Managers are trainers

The interviews revealed that the junior managers (Manufacturing Team Leaders) at the case company were involved in the delivery of training for the shop floor employees in the various continuous improvement techniques.

Objective for employees

The case study data indicated that all the employees had involvement in continuous improvement activities as one of their personal objectives.

5 CONCLUSION

The research is still on-going, but initial analysis suggests several interesting findings. Initial results suggest that several factors have an influence on sustaining a continuous improvement initiative; these include having a senior management focused on continuous improvement (not only focused by driving it forward), front line employees and middle management expected to make improvements, the preserve of a continuous improvement culture, the use of standardized improvement methods and a standardization of the improvements made. The research also indicates that there are other factors that can impact the sustainability. One area that has been overlooked by previous researchers is the infrastructure for idea selection and processing; if this is not simple, transparent and relatively fast, employees may be discouraged to continuously put forward ideas. Also the excessive focus of the

plant management on the day-to-day activities, especially production output, can cause the employees to concentrate on this and to ignore the improvement work.

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A STRATEGY FOR ACHIEVING MANUFACTURING STATISTICAL PROCESS CONTROL WITHIN A HIGHLY COMPLEX AEROSPACE ENVIRONMENT

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ABSTRACT

This paper presents a strategy to achieve process control and overcome the previously mentioned industry constraints by changing the company focus to the process as opposed to the product. The strategy strives to achieve process control by identifying and controlling the process parameters that influence process capability followed by the implementation of a process control framework that marries statistical methods with lean business process and change management principles. The reliability of the proposed strategy is appraised using case study methodology in a state of the art manufacturing facility on Multi-axis CNC machine tools.

Keywords: Process Control, Process Capability, Multi-axis Machine tools

1 INTRODUCTION

The world is rapidly evolving with new technologies and innovations that are affecting manufacturing. We are in a time of increased miniaturisation, increasing fuel efficiency and higher levels of integration. All these elements combined create a climate that calls for a sustained supply of high precision components (Brinksmeier, 2010).

For these reasons, quality conformance and control are crucial characteristics in the aerospace and defence industry. Additionally, high value materials and the advanced manufacturing techniques lead to components of extremely high production value. Therefore additional emphasis is paid to the avoidance of scrap through increased quality conformance by achieving process control. The advantages for aerospace and defence manufacturing companies adopting a dedicated stance towards high levels of quality conformance and control are many, for example;

- A quicker assembly and fitting process
- Increased interchangeability of parts
- Improved energy efficiency in assembled products (engines, generators)
- Improved product performance

The aerospace and Defence industry is a mass user of multi-axis CNC machine tools because of the scale and complexity of components that the industry requires. However, within this unique manufacturing environment it is very difficult to achieve manufacturing “total process control” from the traditional part conformance perspective. Finite batch orders, typically below one-hundred units, leads to a slow but steady throughput of large components featuring multiple complex features and intricate datum systems. They usually require multiple machining stages in different orientations and

the flexible nature of modern manufacturing systems often dictate different machines for the separate stages (Nau, 2012). As a result, determining the “root cause” of conformance issues or the key influencers of variability will be difficult to achieve. In this respect, when compared to the automotive industry, the aerospace and defence industry is at an obvious disadvantage. High volumes, typically in the excess of the tens of thousands, create a lot of “opportunity” for process engineers to learn, iterate and fine-tune to perfect the manufacturing process. Furthermore high volumes justify a dedicated manufacturing line for the manufacture of specific components, whereas the low volumes of the aerospace industry calls for a “flexible manufacturing” approach where multiple components can be made on the same line or in the same production cell, and the manufacturing system can quickly reconfigure to accommodate a varying demand (Lauzon, 1997).

There are also cultural elements that contribute to the difficulty in achieving process control. Variability reduction, process control and other initiatives that involve elements of change management are particularly difficult to establish in an aerospace and defence manufacturing setting. Love(1995) suggests that there are many reason for this, but typically because companies are unable to quantify the cost and benefits of quality and variability reduction efforts, and also quantify the benefits of process improvement efforts (Love, 1995).

Research by Ho (2008) into the success of manufacturing companies incorporating variability reduction programs such as Six Sigma found that there were five success factors in its implementation, namely:

- Top management commitment and participation.
- Formulating projects and programs based on customer demand.
- The use of data analysis with data that is easily obtainable.
- Investment of essential resource.
- Incentive/reward systems.

It is also stressed that without a strong project management competence within the organisation there is a strong possibility that the in-corporation of a variability reduction strategy or program will fail (Antony, 2002) (Kwak, 2006).

Hence a new strategy is required to achieve process control that is underpinned by fundamental statistical process control and lean principles, whilst tailored to CNC Multi-axis Machining Manufacturing environments. The approach also needs to integrate elements of change management to overcome cultural factors that often suppress process improvement initiatives. The proposed strategy consists of three elements as shown in Figure 1. The first element provides the theoretical foundation that the other two are built upon. The second provides the principles and practice that form the framework. The third provides the deployment process that guides the business in the establishment of the process control framework and also on the journey towards process control.

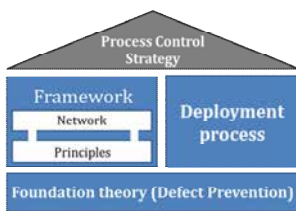


Figure 1: The proposed process control strategy

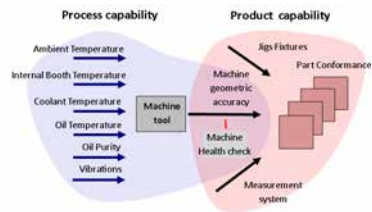


Figure 2: Process parameters

2 ELEMENT ONE - CONTROLLING PROCESS PARAMETERS

As discussed earlier in this paper, achieving total process control is extremely difficult to accomplish in manufacturing lines consisting of multi-axis machine tools. A solution to this problem is proposed by refocusing control efforts away from the “product” and concentrating on to the “process”. If we successfully exert enough control over all the stages, sub-processes and parameters of a manufacturing system, this should enable confidence that the system output will be within acceptable limits (Crosby, 2006).

However, firstly the terminology needs to be defined. Within the aerospace and defence industry the term “process control” or “process capability” is used widely and is commonly used to reflect an entire manufacturing lines ability to produce a conforming output unit. This is neither right nor wrong as definitions vary between authors and academics. However, for the purpose of this paper and the proposed framework:

- **Product Control/Capability** is the ability of the manufacturing process to produce a conforming component.
- **Process Control/Capability** is an ability of a process to produce an output within acceptable limits.

Adopting these definitions, a CNC Machine tool is now recognised as a process. Therefore, from a machine tool perspective, process capability can be defined as the machines ability to consistently operate with a geometric accuracy within predefined acceptable limits.

Embracing this change in perspective, it becomes clear that by improving and controlling individual “Processes” within a manufacturing line, then by consequence we will improve the product capability. In order to control a process, we must control the process parameters. As illustrated in Figure 2, process parameters are input factors that influence the output of the process. Machine geometric accuracy is one parameter that contributes to “product capability”, and in-turn, geometric accuracy is controlled via input parameters to the CNC machine tool. This strategy is commonly referred to as defect prevention because of the specific effort to eliminate process based defects.

Typical multi-axis CNC machine tool process parameters include coolant temperature, warm-up time, vibrations, ambient temperature and oil purity. A variety of condition monitoring techniques can be used to continually assess and control these process parameters, such as thermocouples, humidity probes and data loggers. CNC machine tool “health checks” can be used to determine the error of individual axis movements. The “Renishaw ball” is a linear variable differential transformer (LVDT) that independently measures error in movement in the XY, YZ and XZ planes.

This approach enables this strategy to overcome the constraints of low volume part throughput. Both the machining process parameters and the machine tool geometric accuracies can be monitored and controlled independently of component throughput. Using condition monitoring techniques we can monitor and collect data from the process parameters at a frequency of our own discretion. This can provides process engineers with sufficient data to gain understanding and thus exert influence over the behaviour of the process, striving towards process control.

3 ELEMENT TWO - THE PROCESS CONTROL FRAMEWORK

The process control framework is an element of the manufacturing Failure Mode Avoidance Strategy. Its aim is to provide the using manufacturing company with a clear strategy that enables efficient and effective process control for processes inclusive of multi axis machine tools. It marries robust statistical technique, quality management and assurance requirements, lean and reliable business process design and change management principles. The strategy is underpinned by a collection of principles and a network that maps the framework on to an organisational manufacturing process.

This Framework was developed, trailed and demonstrated at BAE Systems (Military Air and information), in a state of the art hard metal CNC machining facility housing multiple CNC Machining Centres and a flexible manufacturing system.

The governing principles form the foundation of the framework and can be sub-divided in to two categories, namely Cultural and Technical.

Cultural

- **Training and terminology:** Ensuring all terms and definitions are aligned and all employees in the manufacturing facility having a common understanding between product and process control/capability.
- **Management Driven:** Senior management owns the process and is visibly involved in its management.
- **Defined roles and responsibilities:** Governed by senior management and enforced via operations, roles and responsibilities are consistent defined and visible.

- **Visual management:** Visually displaying performance, strategy and current status help employees at all levels understand how their labour contributes to the wider strategy.
- **Role Based Training:** With regard to the framework, individuals are trained in the skills and techniques that they require to complete their respective tasks.

Technical

- **Embodiment of Statistical Process control:** Ensuring that statistical process control and Six Sigma principles are at the centre of the construction and use of the framework.
- **Iterate and refine controls:** Driven by data, iterate and refine the controls of the framework to strike a balance between the extremities of being sensitive enough to capture issues and errors, and being too sensitive in that the framework triggers costly “false alarms”. This principle is particularly important for manufacturing engineers when governing the sensitivity of control limits.
- **Software solutions:** The framework provides a template for application. Software solutions are the best way to approach the application of the framework in to a manufacturing facility.
- **Smart perspective interface design:** Activities where a stakeholder is interacting with the framework are designed from the perspective and requirements of the stakeholder.
- **Central issue’s register:** One central issues register that is used as a depository for all process parameter and geometric accuracy issues. The register is used to store, manage and organise, allocate and control process issues and actions.
- **Tailoring:** The principles and network should be used in a guidance capacity as opposed to a manual. Each business or manufacturing facility, have unique traits and ways of working. In order for this strategy to be effective it is crucial that the organisation tailor the tools and technique to meet their own current need.

The network uses these principles and provides the skeleton structure which enables the framework to be integrated in to a typical multi-axis CNC machining facility. The network is illustrated in Figure 5. Following defect prevention theory (Handfield, 2008), the network is a tailored design aimed to provide the most effective, lean and efficient method for measuring and controlling process parameters.

A prototype was developed as a Microsoft VBA database although other software solutions can easily be pursued. A paper based system can be used, however software solutions provides the most efficient and effective method of applying the framework.

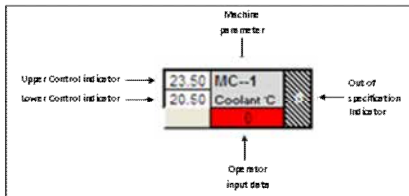


Figure 3: Operator data input box

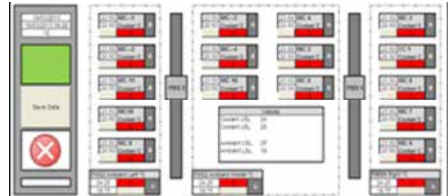


Figure 4: Interface Layout

The framework encourages human interaction within the process with regard to the measurement, collection and assessment of data as opposed to total automation. This is to ensure that issues are escalated timely and there is increased ownership of the process. The smart user interface design principle should be adopted to ensure that the collection and assessment of data does not become arduous. For example, in trialling this strategy at BAE systems, a simplified “box template” method was integrated into the software solution, see Figure 3. The operator simply enters the value then clicks the save button and the system will then indicate to the operator if the unit of data has exceeded or fallen below control or specification limits. The interface was designed to replicate the format of the shop floor so the operator would benefit from the familiarity of the layout making the software less intimidating and more user friendly, see Figure 4. The data is also saved and stored for later engineering analysis. This method also aligns with the role based training principle, recognising that

the shop floor operator is only required to recognise if the value is within acceptable limits, whereas the manufacturing engineer is required conducting more detailed statistical analysis.

Guided by the visual management principle the capability dashboard summarises the data measured and collected and provides an overview of the facility performance in terms of variability of process parameters. This will motivate the shop floor in terms of collecting data because they can see the purpose and outcome of their efforts. The senior management would also use this as a management tool to monitor and control the facility from a high-level.

The network enables clarity of roles and responsibilities and ease of access for the each user. For example the network provides the manufacturing engineer (as illustrated in Figure 5) with the ability to monitor, analyse and exert control of over multiple process parameters from one central hub and then summarise performance to senior management who have the responsibility and authority to govern and manage the entire process.

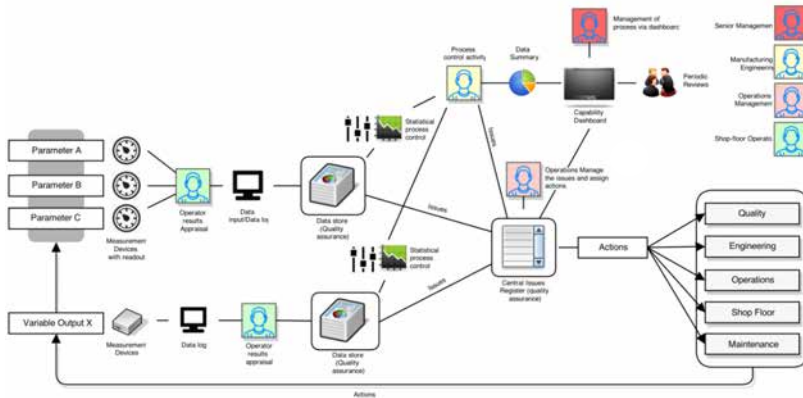


Figure 5: Process control network

The central issue's register is the anchor that binds together the entire network and facilitates process control by managing and controlling corrective actions that are fed from the CNC process parameters. Managed by operations working under the authority of senior management, the central issue's register completes the control loop enabling the reduction of variation in process parameters.

4 ELEMENT THREE - THE DEPLOYMENT PROCESS

Process improvement and variability reduction initiatives and programs often fail to integrate into traditional manufacturing operations for many reasons; one of the main suspected reasons is that whilst these programs are strong in academic and strategic theory, many of the variability reduction efforts lack robust project management technique. As a consequence the results realised are often apart from what was expected. The deployment process establishes detailed controls throughout the process of integrating the framework into the organisation to ensure that process control is achieved manufacturing (Neuendorf, 2004).

There are four main stages to the deployment process. The pre-process stage is primarily for the setting up of the mechanisms that enables successful project management. Tasks include the allocation of roles and responsibilities, creating a high-level project plan for the current and subsequent stages and clarifying the objectives. The aim of the first stage is to identify priorities and plan the control of the process parameters. It involves workshops with the process subject matter experts. Methods of measurement for each process parameter are identified and plans are put in place to install them. Stage two is the application of the framework in to the manufacturing facility according to the project plan created in stage one. As already stated the framework should not be holistically applied, rather tailored to the using organisation's specific need to ensure that the most can be gained from it. Stage three is enabled when the framework is in place and the measurement of the process parameters behaviour/performance is enabled. Therefore a baseline for performance can be determined. This

baseline can then be used to set quantitative objectives for process improvement. Progress against these objectives can be monitored via the framework controls. The deployment progresses into stage four once a satisfactory outcome of stage 3 is reached, i.e. the objectives have been met or the chairman of the process is satisfied with the improvements made.

5 DISCUSSION AND CONCLUSIONS

The framework described in this paper was deployed in a flexible manufacturing facility which houses multiple multi-axis machine tools. The facility produces hard metal components of high value and complexity to the aerospace and defence industry. The deployment of the framework was mostly successful. The pre-process stage was very effective in overcoming the project management woes that commonly hinder variability reduction efforts in manufacturing facilities. Aspects such as the pre-project purposefully being separate from the deployment stages provides flexibility in ensuring that the deployment is scoped and tailored properly to meet the current needs of the facility. Rules such as the project high level plan and start date not being detailed until the “end product” is defined were effective in ensuring that a robust project management infrastructure was in place before the deployment began. Generic detailed high level deployment plans enabled teams to develop a bird’s eye perspective of the whole implementation and raised awareness of progress towards a destination, rather than the aimless journey that plagues many process improvement efforts.

The visibility of the process performance and parameter performance through the central capability dashboard also provided vital stimuli for cultural change. Once involved teams could visibly see the outcome of the fruits of their labour, then this eased much of the potential resistance to the implementation of the strategy and system. Technically the system was also effective. It enabled an overview of performance for all process parameters on one summary dashboard providing Cpk values for high level management. It also provided greater detail for manufacturing engineers to scrutinise and exert control over the quality parameters.

In conclusion, the system’s performance in the provision of a framework that enables process control and realisation of capability is satisfactory. The strategy has proved to have the ability to both react quickly to process errors and ensure escalation, and also drive strategic change through the logging of process errors. The strategy plays a major role in driving cultural change in the using organisation. However further time and data is required to fully realise the benefits and value of the strategy to this unique manufacturing environment.

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STATISTICAL PROCESS CONTROL IMPLEMENTATION IN THE FOOD INDUSTRY: A SYSTEMATIC REVIEW AND IMPLICATIONS FOR FUTURE RESEARCH

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ABSTRACT

This study is to illustrate a systematic review application in investigating common issues emerging from Statistical Process Control (SPC) implementation in the food industry. A total of 34 journal articles were rigorously selected from four databases and reviewed. The most common themes emerge in SPC implementation in the food industry is the benefits while the remaining themes are motivation, barriers and critical success factors (CSF). This review found that the evidence of SPC implementation in the food industry is beneficial; however, a lack of both awareness and guidelines relating to SPC implementation in the food industry has resulted in a slow adoption. This systematic review concluded that there is a crucial need for further research into the SPC deployment aspect addressing how to deploy SPC in the food industry in a systematic manner.

Keywords: Statistical Process Control, Food Industry, Systematic Review, Operation Management

1 INTRODUCTION

It has long been acknowledged that the benefits of Statistical Process Control (SPC) can be expanded to the industrial processing industry and has an obvious significant share in quality aspects of manufacturing industry especially the food industry. The quality control in the food industry is scientifically related to technology, sensory attributes, physical, safety, chemical make-up and nutritional value (Grigg and Walls, 2007).

Food technologists and scientists have been challenged by the variations existing within food production for more than 80 years. The foundation of statistical quality control (SQC) was partly established through work within Guinness breweries, by a technologist and statistician, W.S. Gosset who clearly demonstrates opportunities of SPC element implementation in the food industry (Grigg and Walls, 2007 and Surak, 1999).

2 METHODOLOGY

A systematic review was applied to investigate issues emerging in SPC implementation within the food industry published between 1990 and 2012. Although SPC was initially pioneered by W.E. Deming in 1950 who elaborated on the principles developed by W. Shewart in 1924, it was not until 1980 that the Western manufacturing industry rapidly adopted the technique for their applications and later the first article of SPC in the food industry 1990 was published (Srikao et al., 2005).

Developing the research objective is the first fundamental step of this systematic review. In order to set the objectives, review questions were established. The suggestion leads to the application of the CIMO (context-intervention-mechanisms-outcomes) framework (Tranfield et al., 2003).

CIMO is the management study version of the PICO (population-intervention-comparisons-outcome) framework in healthcare to formulate the review questions and specify studies.

Articles searched in this study also included those listed in the key article bibliographies. After screening the key articles and developing review questions, key words for searching inputs in the database were generated. In a systematic review, the outcome of the decisions in the planning phase will be reported in a formal document called review protocol (Tranfield et al., 2003). Therefore, in the review protocol, the review scope entails questions and objectives of the review, background, inclusion and exclusion criteria, language of article, search and selection strategy and study design (Tranfield et al., 2003). The information in the review protocol will be used through the rest of the review process.

The search of the research literature was undertaken through four databases using Boolean logic and parentheses to generate the following search strings: [(statistical process control) OR (six sigma) OR (total quality management) OR (quality control) AND (food industry) OR food OR agricultur* NOT service] or (total quality management) AND (food industry OR food OR agricultur*)) OR (statistical process control) (food industry OR food or agricultur*)) or (six sigma) AND (food industry OR food OR agricultur*).

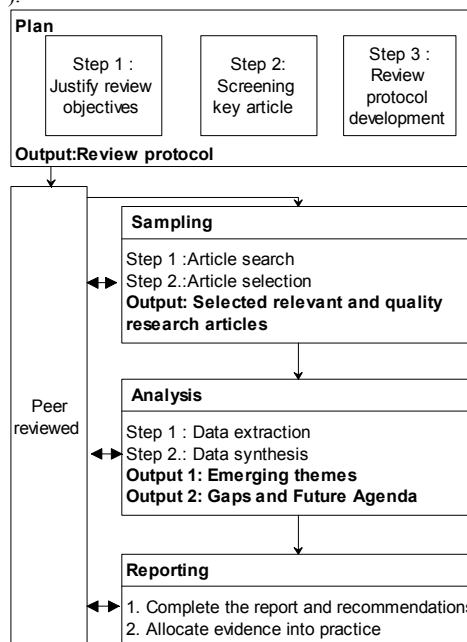


Figure 1: Summary of systematic review process

The databases used are Emerald Insight, IEEEExplore, Science Direct and ABI/Inform. Although, Igenta Connect and JSTOR were initially considered but dropped due to a very low number of article hits within the scope of this review and all remaining relevant articles listed which were redundant (duplicate) with articles found in other databases were excluded as well.

The advantage of conducting a systematic review is to reduce bias in the selection by the comprehensiveness of the search strategy and transparency of the relevant articles (Figure 2.) included in the review (Tranfield et al., 2003). From CIMO logic, inclusion criteria of context are food industry, food manufacturing, food processing and food production while the exclusion context is found in food service and laboratory trials. Interventions included in this article are SPC, Six Sigma, TQM and Continuous Improvement (related to SPC). However, quality function development (QFD), Zero Defects and Just-In-Time (JIT) are excluded due to the absence of SPC techniques underlying

the respective methods. Inclusion criteria (Mechanisms) involve aspects of SPC introduction and implementation efforts and the exclusion criterion is mathematic theoretical development articles. Inclusion criteria (Output) are outlined to include issues emerging in SPC implementation and exclude articles with an outcome of mathematical theory. Only complete articles in English will be assessed while book reviews, dissertation, letters, commercial web pages and brochures are excluded as the contents of such sources are insufficiently assessed by the experts.

In the selection process (Figure 2), titles and abstracts were reviewed to select the articles based on inclusion/exclusion criteria and articles, which meet exclusion criteria will be discarded. Full articles of the remaining selected articles were retrieved for full article screening and discarding of the articles that did not meet inclusion criteria. Similarly, the same articles appearing several times (duplicate) due to the use of various database searches were excluded.

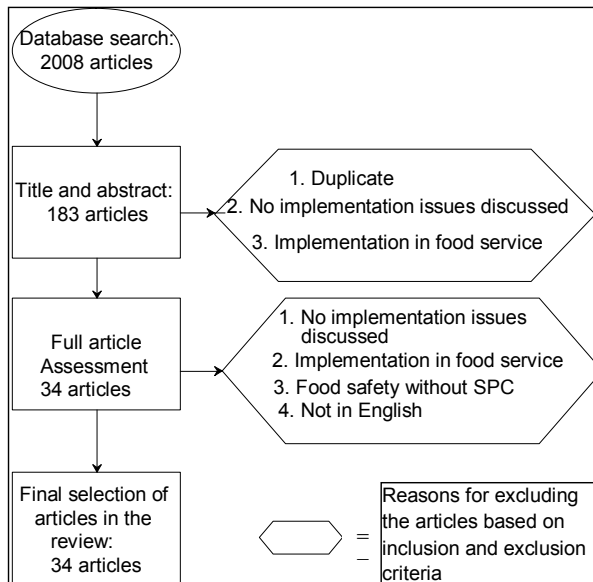


Figure 2: Article selection process

Systematic review does not only offer an exhaustive literature review, but an assessment of quality criteria was also carried out. Quality appraisal was conducted which focuses on whether the result of the study is reliable, a standard procedure in systematic reviews (Booth et al., 2012). The form for quality appraisal, which represents an internal validity, was developed and tested and as for external validity, impact factors or ranking of the journal can be applied.

The reviewer decided to develop a data extraction form using inclusive or selective extraction of the qualitative findings. This approach is more comprehensive and resource intensive. This approach offered only particular types of data that are extracted, such as data meeting pre-specified quality standards, data that are supported by interviews or observations or data related to specific issues or questions. Considering articles collected in this review are based on implementation issues, which mainly involve observations and interviews, this data extraction approach is the most appropriate.

Following this, to ensure data consistency, the author reviewed data extraction forms to clarify and check for any missing or incomplete review subsequently initiated by data synthesis, which was then reviewed by the team. The extracted data were then transferred descriptively and thematically containing key issues of SPC implementation within the food industry. Thematic analysis was conducted by using a data extraction form where articles were coded using Nvivo qualitative research package software (Booth et al., 2012). This technique was chosen instead of meta-analysis due to the

qualitative nature of this review question. However, there is no standard manner of assessing and synthesising operations management research, as it is derived from diverse epistemology philosophies, and proposed for different types of audiences (Dixon-Woods, 2006).

3 RESULTS AND DISCUSSIONS

The first two SPC implementation articles in the food industry were published by Bidder (1990) and Sanigar (1990) in which they both show the experience of introducing and implementing SPC in confectionery and sugar production companies. In the food industry, SPC has been applied for process trend analysis (Mataragas et al., 2012), quality control and monitoring (Gauri, 2003). Recently SPC was also used for food safety purposes while some have incorporated SPC with other quality initiatives such as HACCP, Six Sigma and Design of Experiment (DOE). This result depicted how SPC can be applied as more than merely a monitoring and control technique in the food industry.

The review of the selected studies shows that benefit (34.14%) is the most commonly discussed topic in SPC implementation in the food industry (Table 1). The most reported benefit is food manufacturers' ability to reduce variation in their process and this also led to other related benefits as stated by Schippers (2001) that in order to achieve other benefits, variations in processes have to be controlled in the first place.

Table 1: Benefits of SPC implementation in the food industry

Benefits (%)			
Variation reduction	18.18	Improved customer satisfaction	6.06
Cost saving	15.15	Business growth	6.06
Defect prevention	12.12	Predicting process behaviour	6.06
Increased information from data	9.09	Increased quality awareness	3.03
Increased level of knowledge	9.09	Reduce product giveaway	3.03
Improved decision making	9.09	Consumer confidence	3.03

The popularity of SPC within quality management practice is generated by a wealth of publications dominated by the benefits of its implementation. Comparably, the reviewers did not find any study that reported SPC failure cases, which may be due to publication bias. The reviewers strongly believed that reports describing the failure of SPC projects and studies would significantly contribute to SPC implementation literature.

The failure and slow adoption of SPC implementation may be caused by various barriers (Table 2). There are many cases reporting that lack of statistical knowledge not only causes the failures of SPC projects (Hersleth and Bjerke, 2001) but that it also contributes to the fear of SPC implementation within the food industry. Appropriate training sessions are able to improve knowledge and awareness of SPC in the food industry (Grigg and Walls, 2007) and subsequently generate successful SPC projects.

Table 2: Barriers of SPC implementation in the food industry

Barriers (%)			
Lack of appropriate statistical knowledge	26.09	Lack of empowerment culture	8.70
Lack of management support	17.39	Lack of continuous learning	4.35
Lack of interest	13.04	Lack of allocated time	4.35
Lack of guidelines and manuals	8.70	Resistance to change	4.35
Lack of in-house expertise	8.70		

According to the results in Table 3, most food companies are aware and motivate to improve their business through quality in which variations are recognised as the crucial issue. Nonetheless, most of quality initiatives application in the food industry is circulated to comply with food safety regulations since they are mandatory in the first place (Grigg and Walls, 2007) which forced many food producers to apply quality initiatives such as SPC in the production line and the company as a whole.

Table 3: Motivations for SPC implementation in the food industry

Motivation (%)			
To reduce variability	17.5	As defence for prosecution	5.0
Legal mandate	12.5	To improve company's image	5.0
Market competition pressure	10.0	To improve operational performance	5.0
To improve productivity	10.0	Customer pressure	5.0
To gain consumer confidence	7.5	Desire to gain knowledge	5.0
To gain more information from the data	7.5	As a validation technique	5.0
Financial force	7.5	To characterise the process	2.5

There are only two papers that specifically addressed CSF of SPC deployment in the food industry. Hersleth and Bjerke (2001) developed a contextual model of statistical thinking which entails explanatory variables affecting the extent of statistical thinking as depicted in Table 4. The other study (Grigg and Walls, 2007) divided SPCs CSFs in two categories; internal and external facilitators.

Table 4: Facilitating factors for successful SPC implementation in the food industry

Critical success factors (CSF)	
The factors cited by both articles	Description
Management commitment	The most prominent CSF for any CI initiatives
Continuous education	Formalised and regular quality training for SPC implementation.
Organisational resource base	Relates with financial, human, technological, physical resources.
Data collection procedure	A procedure specific for sampling activities from process, production and product attributes.
IT system availability	Availability access to PC, intranet and software solution.
The factors cited by single article	Description
Empowerment	The opportunity for each employee to influence his or her own working environment.
Quality maturity level	The adoption of the established quality initiative (TQM, Six Sigma, Lean, Six Sigma, ISO 9000, Quality circles).
Strategy for quality improvement	Organisation's goals and strategies for quality improvement.
Ability to change the culture	Degree of cooperative culture, interest, and acceptance for new ideas and motivation for statistical thinking.
Project prioritisation	High impact and urgent projects should be given the priority for quality improvement initiative implementation projects.
Employees competence level	Staff's level of education and knowledge of statistical technique.
Organisational size	The smaller companies used fewer statistical techniques compared to bigger companies
SPC facilitator	SPC facilitator generally has the repository of knowledge on SPC methods and systems.
Availability of relevant information	(Department of Trade and Industry) DTI code of practice is the major source advising SPC deployment in UK food packaging.

Management commitment is the most important factor not only in SPC implementation but mostly in other quality improvement systems and methods as well (Antony and Balbontin, 2000). However, since there are very few articles related to this issue, there is insufficient evidence to generalise the CSF of SPC implementation in the food industry.

4 CONCLUSIONS AND FUTURE AGENDA

The number of studies found is considered relatively low compared to other quality improvement initiatives and systematic reviews of SPC application in other industries. This limitation reflects the crucial need for research on the SPC deployment aspects within the food industry. The articles specifically discuss on SPC implementation has declined in recent years due to the increasing of Six Sigma application for process improvement purposes which SPC is embedded as one of the main technique within the DMAIC methodology. This review validates that there is potential for continuous quality improvement and financial advantage in implementing SPC in the food industry and more

research with rigorous design and detailed reports is needed to boost the methodological base for the implementation of SPC techniques within this industry. There is a significant gap in current literature where the control of operation is listed one of the criteria in food industry's good manufacturing practices (GMP) which match with the SPC's philosophical base, there is not a specific manual to apply the technique (Costa Dias et al., 2012).

This review shows that the challenging factor in implementing SPC for non-statisticians is not only related to theoretical issues but also involves nonmathematical levels such as cultural and human issues. The reviewers strongly suggest that this led to the fact that given a good data collection method, sufficient knowledge of systems, tools and methods, sufficient resources and high motivation, the key to success remains complex in the food industry. Therefore, there is a strong demand for investigation into SPCs CSF studies within the food industry where such research is insufficiently investigated up to this date. There are also very few guidelines available for SPC team formation where this has caused a great confusion, especially for the first time SPC users.

The reviewers strongly suggest that a roadmap should be developed which depicts practical food industry application guidelines incorporating all aspects of SPC implementation and the food industry including training and continuous education guidelines since from the review, up until now, there are no standardised training outlines developed for SPC implementation. Although there are limitations and impeding factors in implementing SPC within the food industry, SPC is proven as a powerful technique to manage quality changes in the food industry provided the implementation is driven towards a clear vision and goals and its deployment is facilitated by a strategic and systematic approach.

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DISCRETE-EVENT SIMULATION OF PROCESS CONTROL IN LOW VOLUME HIGH VALUE INDUSTRIES

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ABSTRACT

This paper presents a new method of process control for set-up dominant processes. This new method known as Set-up Process Algorithm (SUPA) was compared with existing industrial practices and statistical techniques in the literature. To test the method's robustness, a generic discrete-event simulation model was built. This model was used to test four different statistical approaches to process control. It was concluded that SUPA offers a method of process control for set-up dominant processes, which is easier to apply than classically derived SPC approaches, by using simple rules and a traffic light system based on design specification. Simulation analysis shows that SUPA: is more sensitive, at detecting an incapable process as it will monitor more units when a process is less capable; is more sensitive than PRE-Control at detecting mean shifts in a process. SUPA is also a nonparametric methodology and therefore robust against processes with non-Gaussian distributions.

Keywords: pre-control, statistical process control, process set-up.

1 INTRODUCTION

To improve the quality from high precision processes, many companies are implementing Six Sigma process improvement methods (Julien & Holmshaw, 2012). Six Sigma has been successfully used in high volume manufacturing (Bhuiyan & Baghel, 2005). However, the large amounts of data required to perform statistical tests associated with Six Sigma have led many practitioners, operating in low volume environments, to abandon objective analysis in favour of a subjective approach (Julien & Holmshaw, 2012). This is accomplished by utilizing the engineer's opinion over data driven improvement.

A current concern, within Six Sigma, is Control method implementation for low volume processes. Typically, low volume processes are high precision ones, capable with respect to Critical-to-Quality (CtQ) parameters for the production run duration. The dominant variation source between batches is linked to adjusting the process to the CtQ specification centre during set-up, resulting in set-up dominant processes (Juran & Gryna, 1988). It is common to use "rule of thumb" methods to control such processes. Otherwise, implementing no control methods, ignoring the problem.

This type of problem with "rule of thumb" methods was observed by (Carter & Butler, 1996). This case-study of precision turned components, reported that Control of small batch production had "a heavy reliance on the operator's experience". Instances of variability in a process being induced by the operators making unnecessary changes, were reported.

Two common “rule of thumb” methods identified are First-Off’s and 100% Inspection (Pillet, 1996). First-Off’s measure the CtQ of the first unit produced. However, little process information can be gained from the measurement of a single unit. 100% Inspection measures the CtQ of all units as they are produced. The process is then adjusted after every unit measured, either off-target or out of specification. This results in operators either hunting for the specification centre, or, even worse, allowing defects to occur. In either case, little statistical rigour is applied to the data captured.

2 REVIEW OF CURRENT PRACTICES

In high volume manufacture the application of Statistical Process Control (SPC) has been successful at maintaining the statistical stability of a process. A common SPC approach for a variable measure is the $\bar{X}$ & R chart, plotting the mean ($\bar{X}$) and the range (R) of a subgroup of sampled units against capability based control limits. Then while a process is being monitored, if $\bar{X}$ falls outside its control limits, it shows there has been a statistically significant change in the process mean. If R falls outside its control limits, it shows there has been a statistically significant change in the process variation.

In low volume processes there are issues with SPCs application. This is a result of few units being produced in a batch, making it impossible to gain sufficient data to estimate the process performance.

The process capability metrics C_{pk} and C_p are used to quantify process variation. C_p uses process standard deviation (σ) to estimate process performance against the upper (U) and lower (L) specification, by

$$C_p = \frac{U - L}{6\sigma}. \quad (1)$$

C_{pk} uses σ and process mean (μ) to estimate process performance against U and L , by

$$C_{pk} = \left[\frac{U - \mu}{3\sigma}, \frac{\mu - L}{3\sigma} \right]. \quad (2)$$

A small batch $\bar{X}$ & R chart using a five unit decision procedure is given in (Pillet, 1996). The $\bar{X}$ & R charts control limits are recalculated as the subgroup size increases from one to five units. This overcomes the problem of waiting for a complete subgroup to indicate an issue. A decision can be made on the need to re-centred a process after one unit and whether there is too much process variation after two units. A disadvantage with this method is the necessity to calculate control limits on subjective assumptions, engineering knowledge, or possibly scarce surrogate/historical data.

Acceptance Control Charting (ACC) (ISO/TC 69/SC 4, 2010) use design target and specification limits to base control limits. They define acceptable process limits, which draw lines based on an acceptable risk of a false fail (α -risk). Also defined are acceptance control limits, whereby any sample mean ($\bar{X}$) above the upper or below the lower acceptance control limits, deems a process as non-acceptable. A version of ACC, from (ISO/TC 69/SC 4, 2010), bases upper and lower acceptance control limits on: the specification target (μ), process standard deviation (σ) and the z -value statistical constant, retrieved from a standard normal table for the required α -risk.

This method is slow to respond to off-target processes as it depends on the collection of samples in a subgroup. Derivation of its control limits also require an estimation of process variation. As with small-batch $\bar{X}$ & R , ACC makes the assumption that the process conforms to a Gaussian distribution.

A different, less used approach to set-up dominant processes Control, is stage 1 of PRE-Control (PC). Unlike classic approaches to SPC, PC makes no assumption of the underlying distribution of a process (Juran & Gryna, 1988; Ledolter & Swersey, 1997; Steiner, 1998). Its objective is defect prevention, to ensure any validated set-up has a minimum C_{pk} of 1.33.

PC uses a traffic light system to divide the design specification of a measured CtQ. The central region covering 50% of the specified tolerance is designated as the Green Zone. The regions which cover 25% of the specified tolerance respectively, between the Green Zone and the specification limits are the Yellow Zones. The regions outside the specification limits are the Red Zones.

Units are sampled and their measured CtQ categorized as Green, Yellow or Red. To validate the new process set-up or an adjustment made to an existing process, stage 1 rules are applied, Table 1. Consecutive units are sampled from the process. If a sampled unit is Red it signals that the process is off-target. Two consecutive units in the same Yellow Zone signals that the process is off-target. Two

consecutive units in opposite Yellow Zones signals the process variation is too great. Five consecutive Green units demonstrate the process is capable and it is allowed to continue without further checks.

Table 1: Outline of Stage 1 (Validation) Decision Rules for PRE-Control

Sampled Units	Observation	Action
1	Red Unit	Stop and Adjust
1 2	Two Consecutive Yellow Units Same Side of Target	Stop and Adjust
1 2	Two Consecutive Yellow Units Opposite Sides of Target	Stop and Investigate
1 2 3 4 5	Five Consecutive Green Units	Continue Process

A significant issue with PC, is that as the process becomes more Capable, i.e. C_p increases, a greater percentage of off-target processes are qualified. In fact as the C_p of a process approaches 2.33, 98% of product will qualify the stage 1, even if the process mean is 2 standard deviations off-target.

As the bar has been risen with respect to precision processes, maintaining a C_{pk} of 1.33 is often not good enough. To overcome this, a new method called Set-Up Process Algorithm (SUPA) is described here. Subsequently, in order to assess the effectiveness of small-batch $\bar{X}$ & R charts, ACC, PC and SUPA in a set-up dominant environment, a discrete-event simulation model is used. This model is able to test the respective methods efficiency against processes of varying performance.

3 SET-UP PROCESS ALGORITHM (SUPA)

Given the small run, low volume processes this paper focuses on, with production runs of five to ten units. A new algorithm for process adjustment and set-up qualification is proposed. The method will qualify or adjust a process within five units and will introduce a sliding scale Green Zone. This addition improves the centring of highly capable process within a CtQ specification maximising the limited data. It also provides a link between statistical tolerances and process capability.

There are two types of α -risk: the chance of adjusting an on-target process (“hunting”) and the chance of signalling a capable process as incapable. SUPA achieves 98% confidence for the probability of qualifying a valid process, meaning a 2% α -risk (probability of not qualifying a valid process), by the fact that sampling five consecutive Green units will validate a set-up and two consecutive Yellow units will initiate action to be taken (San Matias, Jabaloyes, & Carrion, 2004). To obtain a value of probability of qualifying, $P(q)=0.98$, for different values of C_{pk} , the probability of sampling a unit in the Green zone $P(g)$ and the probability of sampling a unit in the Yellow zone $P(y)$ need to be used according to

$$P(q) = P(g)^5 \frac{1 + P(y)}{1 - P(y) \sum_{i=1}^4 P(g)^i} \quad (3)$$

Based on Equation (3), the values of the look-up table shown in Table 2 are calculated.

Table 2: Look-up Table of Percentage Green Zone and Minimum C_{pk} at 98% Confidence

Green Zone	C_{pk}
0.471353	1.333333
0.418294	1.500000
0.376396	1.666666
0.313658	2.000000
0.268850	2.333333
0.250926	2.500000
0.235244	2.666666
0.209106	3.000000

Based on the values and data shown in Tables 1 and 2, the SUPA follows the sequence:

1. Select the Green Zone limits for the required minimum C_{pk} , using the look-up Table 2.
2. Sample, Measure and classify the CtQ of consecutive units as: Red, Yellow or Green.
3. Follow the PC rules to validate a process, i.e. a Red unit signals an adjustment is needed, five consecutive Green units signals the process is valid.

The Red zones are always set at the specification limits. The final SUPA chart will have zones and limits as in Figure 1, showing a SUPA chart monitoring a process requiring a minimum $C_{pk} = 2.0$. Given the application, where the cost of adjusting a process is not significant compared to the cost of producing out of specification units, allowing a 2% α -risk is acceptable (Ledolter & Swersey, 1997).

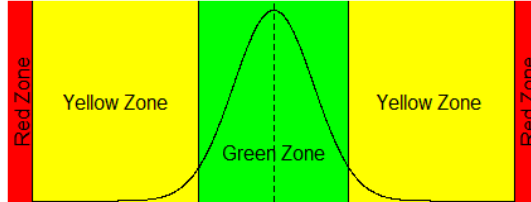


Figure 1: A SUPA Chart monitoring a process with minimum $C_{pk} = 2.0$ using a Green Zone of 31%.

If the process is significantly off-target, SUPA will allow quick adjustments to be made after only one or two units. Whereas, classic SPC would require a subgroup of four or five units before a change. SUPA is a nonparametric method, deriving its limits based on the specification of the product's CtQ being monitored. This allows the Green zone selection to be based on the minimum C_{pk} required from the process to protect the CtQ's statistical tolerances and avoid tolerance stack-up in assemblies. Once five consecutive units are produced in the Green zone, SUPA signals the process is valid.

4 GENERAL DISCRETE-EVENT SIMULATION MODEL

In order to further test the effectiveness of the different methods of validating the set-up of a process, a discrete-event simulation model was built using WITNESS 12. The model simulated a generic process applying a CtQ to a unit, which could represent a lathe machining the outer diameter of a gear. The process has a U and L of ± 100 and a process target, μ_T , of 0. The current process mean, μ , can be offset at the start of the simulation. The model will adjust μ based on the decision rules of the Control method analysed. Capability is set prior to the simulation and remains constant throughout.

The simulation model applies adjustments by finding the mean of the units signalling an adjustment (μ_A). Then it subtracts the difference between μ_A and the process target, μ_T , from the current mean (μ^t) to find the new process mean (μ^{t+1}), i.e.

$$\mu^{t+1} = \mu^t - (\mu_A - \mu_T). \quad (4)$$

The general model can be seen in Figure 2. At the start the experimenter sets the initial parameters of capability and process mean (boxes 1 and 2). The model is allowed to run. Units enter the model (box 3) with a generic process applying a CtQ to each unit (box 4), based on parameters of capability and process mean. The model then samples consecutive units (box 5). Based on the decision rules of the Control method utilised, a decision is made on whether or not the process is valid (box 6). In the case of SUPA, if there were five consecutive units in the green zone the model will be validated. If a model is validated sampling immediately stops (box 7). If the model is not validated, the model decides whether an adjustment is needed to the current process mean (box 8). If an adjustment is not needed sampling continues (box 5). If an adjustment is needed, the mean is recalculated (box 9) by Equation (4). The adjustment is then applied to the process mean (box 2).

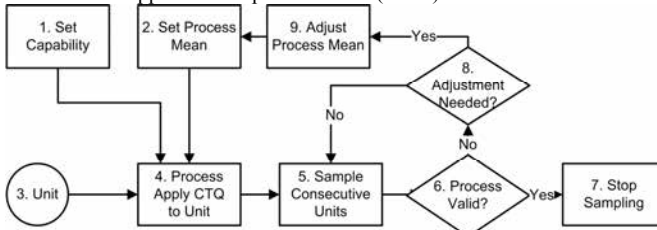


Figure 2: Process flow of general simulation model.

5 DISCRETE-EVENT SIMULATION RESULTS

There are two events which can cause a signal from a Control method: a) when a process is on-target but not capable and b) when a process is capable but off-target. Here, the results are presented from when the simulated Control methods are tested under these conditions.

The simulation will use a process which is producing parts with a Gaussian distribution. Since PC and SUPA are nonparametric methods, they do not make any distributional assumptions. However, small-batch $\bar{X}$ & R and ACC do assume the process has a Gaussian distribution. Simulating a process with a Gaussian distribution offers a fair starting point for comparing the respective methods.

5.1 Process On-Target, but not Capable

The respective methods were tested against a process which was initially set on-target. However, each time the simulation was run it had a smaller C_p and therefore larger process variation. The control methods were all set to monitor a process with a C_{pk} of 2.0. The first run of the simulation had a C_p of 2.0. Each run decreased in the value of C_p , to a final value of 0.667. As these discrete-event simulation models are stochastic, each simulation run had 1,000 replications to minimise deterministic effects of the pseudo-random number generation.

Two questions are posed: a) what is the $P(q)$, despite any adjustments made? and b) how many units does it take to make a decision? These are answered in Figure 3 a) and b) respectively.

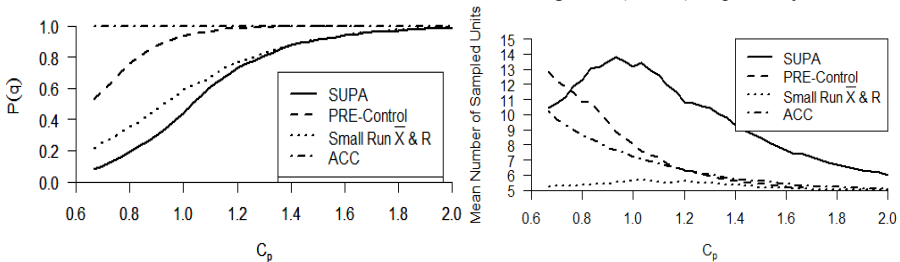


Figure 3: The Effect of Decreasing C_p against a) probability of qualifying ($P(q)$) and b) number of units sampled for SUPA, PC, small-batch $\bar{X}$ and R and ACC simulations.

Figure 3a demonstrates some important points. ACC has no mechanism to indicate that a process is incapable and will eventually validate all set-ups despite the capability; for CtQs which need to be made to a higher C_{pk} than 1.333, SUPA offers significantly improved performance than PC; SUPA has better performance than small-batch $\bar{X}$ & R at detecting incapable processes, at a C_p of 0.667 small-batch $\bar{X}$ & R still qualifies over 20% of set-ups whereas SUPA only qualifies 7%. These results indicate that SUPA is the most sensitive control method for detecting incapable processes.

Figure 3b highlights that as C_p decreases: small-batch $\bar{X}$ and R consistently uses between 5-6 units; PC and ACC use more units, tending towards 13 and 10 units respectively, as C_p approaches 0.667; SUPA uses increasingly more units to make a decision, peaking at 14 units. On the face of these results small-batch $\bar{X}$ & R looks the most efficient method. However, the increased monitoring of SUPA, when a process is less capable, is useful as it increases the sensitivity of detecting an incapable process and reduces the chance of an out-of-specification unit being produced unnoticed.

5.2 Process Capable, but not On-Target

This analysis tested the respective methods against a process which was initially set with a fixed C_{ps} of 1.333, 2.0 and 2.667. Each time the simulation was run at these settings it had a process mean further away from the on-target state. The Control methods were all set to monitor a process with a C_{pk} of 2.0. The first run of the simulation at each setting of C_p started on-target. Following runs began with the process mean further from the on target state by a factor of process standard deviation (σ). Again, each simulation run had 1,000 replications.

The most important question answered was: what was the C_{pk} after a process was validated? This shows how effective the control methods are at centring an off-target process, presented in Figure 4.

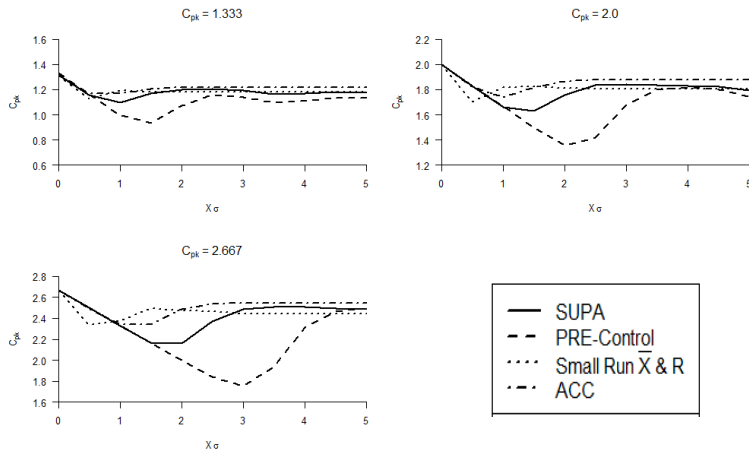


Figure 4: Graphs of final C_{pk} against start positions of process mean as a factor of σ , when the simulation has three different maximum values of C_{pk} , for SUPA, PC, small-batch $\bar{X}$ & R and ACC.

Figure 4 highlights: that SUPA offers improved performance over PC; small-batch $\bar{X}$ & R and ACC have steady performance profiles; SUPA has a dip in performance when a process is one to two standard deviations off-target, however, when a process is less than 0.5σ or greater than 2.5σ , SUPA performs marginally better than small-batch $\bar{X}$ & R .

6 CONCLUSIONS

This paper has presented a new method of Process Control for set-up dominant processes. This new method known as SUPA was compared with existing industrial practices and statistical techniques in the literature. To test the method's robustness, a generic discrete-event simulation model was built. This model was used to test four different statistical approaches to process control of set-up dominant processes.

From this work it can be concluded that SUPA offers a method of process control for set-up dominant processes, which is easier to apply than classically derived SPC approaches. This is done by using simple rules and a traffic light system based on design specification, rather than control limits based on estimated process performance. Simulation analysis shows that SUPA: is more sensitive, than other approaches at detecting an incapable process as it will monitor more units when a process is less capable in its effort to reduce the risk of allowing a defect to occur; is more sensitive than PC at detecting mean shifts in a process. SUPA is also a nonparametric methodology and is therefore robust against processes with non-Gaussian distributions.

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TOWARDS THE DEVELOPMENT OF A MANUFACTURING FAILURE MODE AVOIDANCE FRAMEWORK FOR AEROSPACE MANUFACTURING

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ABSTRACT

A process based management strategy is crucial to enable productivity and cost effectiveness enhancement in high value manufacturing. This paper introduces a Manufacturing Failure Mode Avoidance (MFMA) framework based on four high level steps, underpinned by a series of structured tools to support a structured function-based decomposition of complex manufacturing processes and a continuous flow of information towards the development of robust control plans. The approach draws from experience from the automotive industry where Failure Mode Avoidance (FMA) has been adopted as a strategy to achieve a step change in the effectiveness of business and engineering processes associated with the product creation process. The paper illustrates a pilot implementation of the MFMA framework on a case study for the manufacturing of an aerospace component, followed by a discussion of the broader applicability of the framework and directions for further work.

Keywords: Failure Mode Avoidance, Process FMEA, Robust Process Control Planning

1 INTRODUCTION

Increasing volume and production efficiency of high value / high complexity aerospace parts, components and assemblies requires a robust strategy for the design, development and control of manufacturing processes. This is a significant shift from the traditional emphasis placed upon part control and heavy reliance on complex and accurate machining centres and highly skilled and experienced operators. However, modern aircraft products have increasingly complex parts with tighter tolerances and greater requirements for the interchangeability of components and assemblies. A change to process based management, focussed on the identification and control of critical process parameters, ensuring consistent delivery of parts first time through, is required to meet these demands whilst capably managing pressures to increase production rates in a cost conscious environment.

In order to achieve the transition to a process driven manufacturing strategy, robustness and reliability need to be designed into processes through a deepened understanding of the relationships between desired process outputs and the characteristics which are used to create them (Glodek et al., 2006). As robustness, defined by Clausing and Frey (2005), is “the ability of a system to function (i.e. to avoid failure) under the full range of conditions that may be experienced in the field”, reliable manufacturing processes can be achieved through identification and prevention of potential process failures. For the greatest impact, countermeasures to prevent failure need to be designed and deployed early in the design of manufacturing process when the freedom for change is highest. However, as it is difficult to avoid a potential failure that has not been identified (Kmenta, Finch and Ishii, 1999), a systematic method for the early identification of potential process failures and the deployment of robust countermeasures for their prevention is required.

Failure Modes and Effects Analysis (FMEA) has been extensively applied across industries (Liu et al., 2011) as a proactive failure avoidance tool. FMEA aims to assess and improve the reliability of products and processes by discovering and correcting design or process deficiencies through the analysis of potential failure modes, effects, and mechanisms, followed by a recommendation of

corrective action (Yang, 2007). While Kmenta et al (1999) have recognized differences between many definitions of the term ‘failure mode’, for the purposes of this paper the functional basis suggested by AIAG (2008) has been adopted, i.e. a failure mode is defined as ‘any way or manner in which a product or process could fail to perform its desired function’. Applying FMEA encourages engineers to identify potential failure modes and understand their causes, which enables effective countermeasures to be deployed to prevent their occurrence, thereby avoiding the failure and its associated costs. Despite its widespread application, particularly in the aerospace, nuclear and automotive industries, there are many reported shortcomings with FMEA, such as:

- FMEAs are highly labour intensive and there is a tendency to produce large, cumbersome documents (Bell et al., 1992); FMEAs are often seen to be ‘just more paperwork’ and as a result little benefit is expected (Johnson & Khan, 2003);
- FMEAs often require an extensive time scale to complete the analysis, often incompatible with the set timing and resource allocated (Hawkins & Woollons, 1995);
- FMEAs are not used effectively to support design decisions as failure causes are often not identified (McKinney, 1991), and the deployment of the tool is too late (Webb, 2002);
- Without an organized approach to identifying failure modes, the analysis can become subjective limited by the level of experience and engagement of the engineering team conducting the analysis (Kmenta & Ishii, 1998).

To address these issues, a systematic method is required to facilitate the effective and efficient identification of failure modes early in the design process, allowing preventative countermeasures to be implemented based on their causes.

The Failure Mode Avoidance (FMA) framework discussed by Campean & Henshall (2012) offers a pragmatic approach to robust automotive system engineering design, facilitating early discovery of failure modes through the use of a structured sequence of proven engineering tools that are built around a central FMEA. The strength of the approach is underpinned by the introduction of a structured and systemic approach to function analysis which is focused on capturing interface functions which support the integration of the system. Failure modes analysis is strongly facilitated by the comprehensive function analysis, and it is focused on identification and prioritisation of function failure modes and their causes. This is followed by robust countermeasure development and design verification and validation. By developing a functional understanding of the system, FMA ensures that all potential mechanisms of failure are identified systematically through the design process, thereby facilitating actions for their avoidance. A clear flow of information between the integrated tools maintains scope throughout the analysis, which results in contained, concise and manageable documentation. This process has been proven through industry implementation (Campean et al 2013), and has a strong take up within the automotive industry.

This paper presents the development of a Manufacturing Failure Mode Avoidance (MFMA) framework which adopts the principles and practices of FMA and applies them towards the design of robust and reliable manufacturing processes. After an overview of the proposed MFMA process, a case study of an aerospace manufacturing process is used to illustrate its deployment, followed by a discussion of the effectiveness of the approach and reflection on opportunities for future work.

2 MANUFACTURING FAILURE MODE AVOIDANCE PROCESS

Similar to the FMA framework (Campean and Henshall, 2012, Campean et al, 2013), the proposed MFMA process is structured on four high level process steps and based on the ideology that in order to identify the manner in which a process can potentially fail, it is first necessary to understand how it is intended to “function” in order to deliver the critical part or assembly characteristics. Accordingly, the first step, Process Function Analysis (Figure 1), aims to map the process in a structured top-down approach, systematically identifying the manner in which critical characteristics of the part are achieved and the process factors that can affect each part characteristic as “noise” factors. On this basis, the following step, Process Failure Mode Identification, aims to identify and prioritise potential failure modes of the process as ways in which the process does not deliver the required functions, and to systematically identify causes for potential failure modes in relation to the “noise” factors identified in the previous MFMA process step. The next process step revolves around the development and implementation of effective process improvements and control methods required to avoid the critical

failure modes. Finally, step four – Process Control and Validation, focuses on the deployment of dynamic process control plans (Ford Motor Company, 2004) to validate and monitor on going production, underpinned by the process function and function failure mode analysis, and incorporating any process improvement actions.

Figure 1 summarises the MFMA process and the key tools utilised to support each process step. In order to illustrate the deployment of the proposed MFMA framework a case study has been considered and will be presented and discussed in the following section.

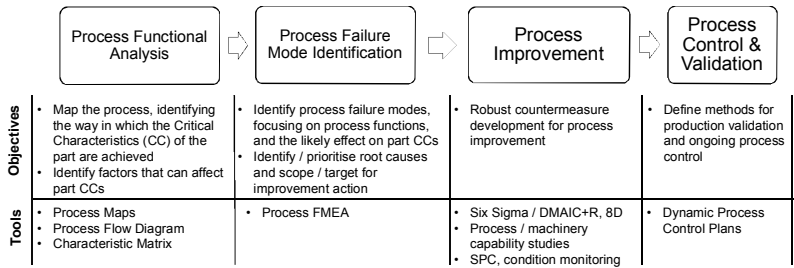


Figure 1: MFMA process framework: steps, objectives and supporting tools

3 CASE STUDY

This case study was based upon a machining process for the manufacture of a stainless steel aircraft bracket using a 5-axis CNC machining centre. This is an existing process that has been used to assess the feasibility of the MFMA framework. The deployment of the process was carried out with support from the engineering team responsible for the operation of the process.

3.1 Process Functional Analysis

Firstly, the inputs and the outputs of the process must be defined in terms of their specific characteristics and the metrics used measure to them. Once this is known, Process Mapping was iteratively applied to decompose the process at successive levels of abstraction into finite operations which provide a succinct description of how and when each of the part characteristic is created, as shown in the Process Map in Figure 2. Through this segregation of activities, the process is deconstructed into manageable components that facilitate the rest of the analysis by specifying each of the individual requirements of the process operations.

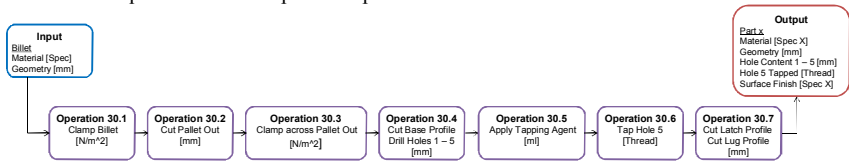


Figure 2: Process Map for the Case Study part

A Process Flow Diagram (PFD) was constructed next, illustrated in Figure 3, adding technical detail which allows the part characteristics to be defined in greater depth. For this case critical coordinates of the components profile are detailed along with hole positions, diameters and tolerances. Furthermore, the process characteristics that create or affect the part characteristics are documented. These are defined as inputs to the process that can be actively controlled and monitored. “Noise” factors or sources of variation are also listed, which are, contrastingly, process inputs that cannot easily be controlled, i.e. they vary but are difficult to monitor or change at will. The format of this document, as the extract shown in Figure 3 depicts, means that these additions are documented against each process operation, which is beneficial as it forms the basis of establishing the relationships

between part and process characteristics. This document also provides the scope and level of resolution for the Process FMEA.

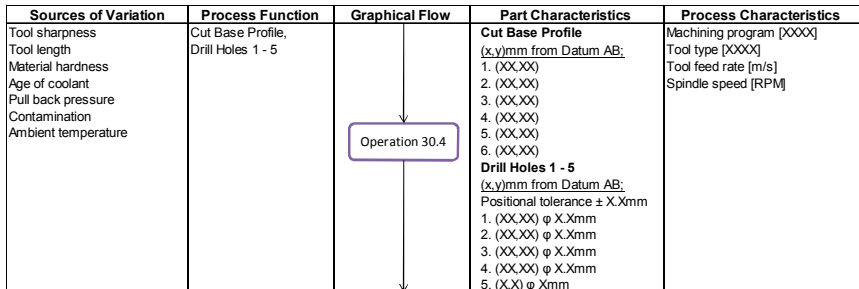


Figure 3: An extract from a Process Flow Diagram

The Characteristic Matrix takes the part and process characteristic information stored by the PFD, identifies the specific causal relationships between them and characterises their nature. By classifying the causal relationship between the part and the process sequence at specific operations, and the effects that they have at subsequent operations, this document provides an important record of the part-process linkages, facilitating total process understanding and supporting the development of the Process FMEA. For instance, as the extract in Figure 4 shows, the part characteristics created in operation 30.4 are used for clamping and location in operation 40.2. As a result, it is identified that the process characteristics used during operation 30.4 have a significant effect on the ability of operation 40.2 to achieve its function.

					Process Characteristics										
					Operation										
					30.1	30.2	30.3	30.4	30.5	30.6	30.7	40.1	40.2		
					Clamp Pressure	Machining Program	Tool Type(s)	Tool feedrate	Spindle Speed	Clamp Pressure	Machining Program	Tool Type(s)	Tool feedrate	Spindle Speed	Quantity of tapping gel
					n/m ²	XXXXXX	XXXXXX	m/s	RPM	n/m ²	XXXXXX	XXXXXX	m/s	RPM	XXXXXX
															Type of tapping gel
															Tap (Tool) Type
															Tapping Depth
															Tool feedrate
															Spindle Speed
															Tool Type(s)
															Tool feedrate
															Spindle Speed
															Deburring tool
															Clamping Pressure
Operation	Function of Operation	Part Characteristic	Metric												
30.4	Cut Base Profile, Drill Holes 1 - 5	Cut Base Profile, (x,y)mm from Datum AB; 1. (XX,XX) 2. (XX,XX) 3. (XX,XX) 4. (XX,XX) 5. (XX,XX) 6. (XX,XX)	[mm] (x,y)		R	R	R	R	R	X	X	X	X		
		Drill Holes 1 - 5, (x,y)mm from Datum AB; 1. (XX,XX) ϕ X.Xmm 2. (XX,XX) ϕ X.Xmm 3. (XX,XX) ϕ X.Xmm 4. (XX,XX) ϕ X.Xmm 5. (XX,XX) ϕ X.Xmm 6. (XX,XX) ϕ Xmm	Position - [mm (x,y)] Diameter - [mm]		R	R	R	R	R	X	X	X	X		

Figure 4: An extract from the Characteristics Matrix

3.2 Process Failure Mode Identification

Supported by the inward flow of information generated by the previous documents, the Process FMEA is effectively segmented into process steps and the part characteristics they create, which aids in the identification of failure modes based on any deviation from these requirements. Figure 5 shows how the knowledge generated in the Characteristic Matrix effectively populates the Process FMEA. Effects and causes of failure modes are derived from examining the process characteristics that are related to the creation of the part characteristics. Identifying causes is further supplemented by the

sources of variation recorded in the PFD (Figure 5). Once specific causes of failure are understood, then robust countermeasures can be effectively deployed to avoid failure. This occurs in the subsequent MFMA steps not included in this paper. Failure modes are ranked according to their severity and the likelihood of their occurrence by using a consistent scale, which allows process improvement actions to be prioritised.

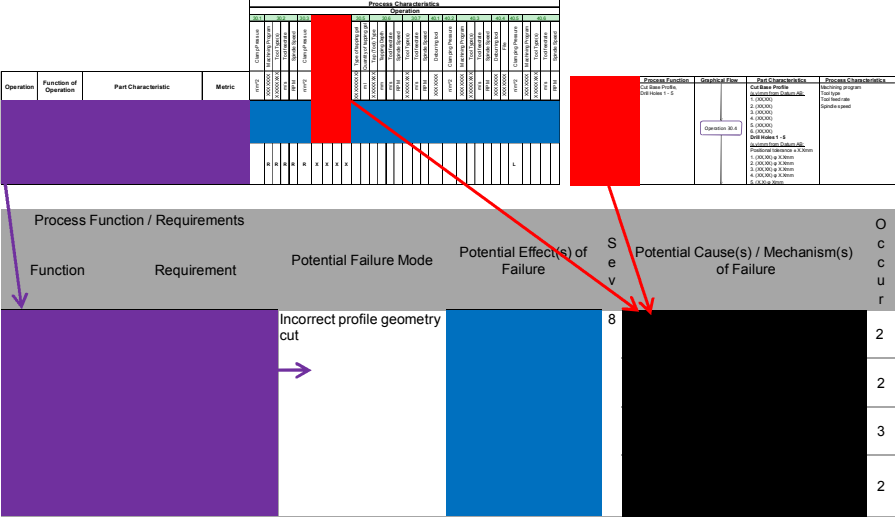


Figure 5: An extract from the Process FMEA, demonstrating the cascade of information from the Characteristics Matrix

4 DISCUSSION AND CONCLUSIONS

The case study provided a good validation of the MFMA framework, showing that it is effective at identifying and mapping the critical part against process characteristics, as the basis for process failure modes analysis, which in turn identifies the scope for improvement action and control plans.

The case study confirmed that the sequence of the tools is appropriate, beginning with a Process Map that deconstructs the process and its requirements into finite operations, which then provide the scope and structure for the following documents, allowing them to be contained and consistent. Furthermore, a strong flow of information demonstrates the integration between the tools, which facilitates effective and efficient completion. This is particularly true of the Process FMEA, as the information used for its population is collected in a logical and structured way, rather than through boundless and disordered brainstorming activities which can prove subjective.

The case study also provided opportunities for potential improvements to be made to the MFMA framework. The causes of failure that are documented in the extract of the Process FMEA (Figure 5) demonstrate a mixed level of detail. For example, spindle vibration is identified as a potential cause of failure, but the pull back pressure on the machine tool is just one of the factors that could contribute to this. As a result, it is acknowledged that the spindle vibration is not only a cause of the failure, but a failure mode in itself at a machinery level, which will have its own variety of causes. Therefore, a machinery FMEA should be conducted in order to identify and prevent all the potential causes of spindle vibration, which will consequently allow the part's geometry to be cut correctly. Without doing so, only the pull back pressure will be controlled, and the failure mode may still occur through an alternative cause. This identifies that there is a requirement for different levels of FMEAs with increasing resolution so that all potential failure causes can be identified at an appropriate level to facilitate the development of countermeasures for their prevention.

Given that the case study was based on an existing process with no specific requirements for improvement, the opportunity to engage process improvement actions was limited. Instead, an audit

has been carried out on the current control plan for the part / processes against the Process FMEA. This validated the MFMA information flow, as any output from process improvement actions will be documented in the FMEA with a revised criticality analysis.

In conclusion, this study has demonstrated that the FMA framework and its principles can be effectively applied in a manufacturing process design context, in order to provide robustness and reliability of processes on the basis of avoiding potential failure modes through the implementation of preventative controls. The main innovations in the approach consists of (i) introduction of a structured top down approach for process decomposition based on functional mapping; (ii) the use of an enhanced Process Flow Diagram and Characteristics Matrix, which identify process “noise” factors and map relationships within the process which include the effect of noise factors; (iii) a strong and coherent information flow between tools, facilitating the development of the Process FMEA, and effectively addressing the pitfalls of conventional Process FMEA deployment. The latter point has been confirmed through feedback from the engineering team that supported the case study. Future work is focused on deployment of the MFMA framework to more comprehensive case studies involving larger teams to fully validate the effectiveness of the approach.

ACKNOWLEDGEMENTS

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BARRIERS TO TOTAL QUALITY MANAGEMENT (TQM) IMPLEMENTATION IN THE MAURITIAN FOOD INDUSTRY

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ABSTRACT

This study was undertaken to determine some of the barriers to the implementation of total quality management (TQM) in the population of medium to large Mauritian food manufacturing companies (MFMC), which were then compared with those identified in Indian and USA manufacturing industries. For this purpose, a questionnaire was sent to the population via e-mail. After carrying out exploratory factor analysis and reliability test, all constructs/investigated barriers were found to be valid and reliable. On comparing the mean ratings for the barriers, the local companies obtained the lowest mean rating that was significantly different ($p < 0.05$) from Indian and USA manufacturing companies. This showed that these barriers had not yet impacted greatly in MFMC. However, the two potential obstacles identified in the Mauritian context were: *employee's resistance to change and frequent turnover of employees*.

Keywords: Food manufacturing industry, Total Quality Management, barriers.

1 INTRODUCTION

The facilitation of trade among countries by the World Trade Organization has enhanced competition in different industries. To attain an upper edge and improve competitiveness, many organizations have realized that meeting customer needs through the provision of quality products and services is a prime key to success. In response, many have adopted quality approaches like total quality management (TQM), which is an integrative management philosophy aimed at satisfying customers and improving continuously the processes. The adoption of TQM practices in many industries worldwide has indeed yielded positive benefits like major cost savings. Yet, many also argue that these results are not easy to achieve.

The implementation of quality programs in many companies has not always been proved to be beneficial. Numerous studies have actually shown that many firms are faced with other barriers that hinder also the development and implementation of TQM (Tamimi and Sebastianelli 1998, Mosadegh Rad 2005, Bhat and Rajashekhar 2009). According to Bhat and Rajashekhar (2009), these obstacles are not restricted to a particular sector but will show up in all sectors – manufacturing, services, government, and education. Therefore, it is important for all firms to understand and avoid these barriers both before and during the implementation of TQM (Tamimi and Sebastianelli 1998).

With regard to the food chain, TQM has been applied worldwide in the food supply and distribution industry. But according to Van Der Spiegel *et al.* (2005), TQM is less frequently used in the food manufacturing industries. Alsaleh (2007) also found that despite the advanced approaches of quality such as TQM play a critical role in improving the competitiveness of companies, the food companies surveyed in Saudi Arabia did not consider them to the extent that was needed. Such organizations might also find it difficult to implement TQM in a satisfactory and effective way due to some obstacles. Hence, the search for the barriers to TQM implementation has become a matter of utmost concern to management of each company worldwide since these barriers vary from one company to another.

Tamimi and Sebastianelli (1998) have identified 25 potential barriers to TQM success based on a review of the quality literature and personal interview with managers in different industries of USA. In 2003, these authors categorized some of these barriers into five main failure factors to TQM namely; inadequate human resources (HR) development and management, lack of leadership for quality, lack of planning for quality, inadequate resources for TQM and lack of customer focus. However, Talib *et al.* (2010) claimed that lack of customer focus is no longer a significant barrier in the current era of digital technology and mass customization since management is closely monitoring it through company-wide information network. Hence, this study will purport to determine whether the other four failure factors are relevant in the MFMC due to the fact that no such study has been undertaken before.

2 RESEARCH METHODOLOGY

2.1 Data collection tool and method

A total of 92 medium and large MFMC that has been recorded in the database available at Enterprise Mauritius and SMEDA in 2012 formed the population size of the study. Sebastianelli and Tamimi's (2003) questionnaire was adapted, and e-mailed together with a covering letter to the head of the quality department of those companies. Respondents were assured of that the information provided would be kept anonymous and confidential.

The questionnaire was structured into two sections. Section one covered the demographic profile of the companies while the other section consisted of four constructs representing the major barriers to TQM implementation. The constructs consisted of 20 statements (Table 2). Each statement was measured through the help of a subjective 5-point likert scale (1, not at all true; 2, slightly true; 3, somewhat true; 4, mostly true; 5, completely true) indicating how true each statement reflected the respondents' company. Of the 92 food companies, 40 quality professionals returned the filled questionnaire via e-mail, indicating a response rate of about 43.5%, which is acceptable for e-mail surveys.

2.2 Data analysis

Construct validity and reliability of the proposed constructs were first determined with the collected data. Construct validity was conducted via exploratory factor analysis (EFA) using principal component extraction with varimax rotation in the SPSS software to identify relevant statements underlying a construct. Statements that had a factor loading of at least 0.30 on their respective constructs were retained in this study because according to Hair *et al.* (2005), they are considered as significant. Next, the constructs were extracted based on the Eigen-value. Factors having Eigen-values greater than one were considered significant and retained while others were dropped (Hair *et al.* 2005). The reliability test was carried out using the internal consistency method, namely the Cronbach's α method. A computed alpha coefficient generated by the SPSS software of at least 0.70 for a construct is considered as acceptable (Hair *et al.* 2005).

Besides, statements for the TQM barriers that were retained after analysis for this study were compared with similar study carried out in the manufacturing sector of India (Bhat and Rajashekhar 2009) and USA (Sebastianelli and Tamimi 2003). Ranks were given to the statements in descending order of the mean ratings for each country, which were then compared. The overall mean ratings for each country were also compared using the least significant difference method.

3 RESULTS AND DISCUSSIONS

3.1 Background of companies

The participating companies, of which 55.0% were of medium size while the others large based on the annual sales turnover as defined by SMEDA (2010), covered well the population surveyed. The respondents were producers of different types of food products notably fish and seafood products (12.5%), beef and beef products (2.5%), poultry and poultry products (7.5%), vegetable and vegetable products (5.0%), fruit and fruit products (7.5%), alcoholic drinks (10.0%), milk and milk products (10.0%), soft drinks/ bottled water (10.0%), cereal and cereal products (7.5%), sweets and sugary

foods (2.5%), ice cream (5.0%), fats and oils (5.0%), spices (7.5%), peanuts (5.0%), and snacks (2.5%). In addition, 50% of the companies were certified to the ISO 9001:2008 standard while 42.9% were in process to the standard's certification. Moreover, 30% of the respondents have reported that the TQM concept has been implemented their company.

3.2 Validity and reliability of constructs

Table 1 indicates that each statement loaded significantly ($p < 0.05$) on its respective construct since the factor loadings exceeded the value of 0.30, signalling high construct validity. Hence, all statements were retained for further analyses. Moreover, all the constructs maintained their original form after EFA because they had each an Eigen-value of more than one. The constructs had also satisfactory reliabilities since the Cronbach's alpha values surpassed the 0.70 threshold (Table 1) except the construct on 'lack of leadership (LL)' that yielded a value of 0.625 but this value was still acceptable since it was close to the threshold value.

3.3 TQM barriers in the local studied context and their comparison among countries

The mean ratings for each construct provided by the local respondents are provided in Table 1. The higher the mean, the more relevant is the barrier. Table 1 indicates that the participants gave an average agreement of slightly true (an approximate rating of 2) to each statement in each construct, indicating that the barriers investigated were not found to affect highly and negatively the implementation of TQM in the food companies under study. Among the studied barriers, the LL barrier scored the lowest mean rating (Table 1). Therefore, it can be pointed out that the top management (TM) of those companies was generally committed to the quality concept and it can be argued that this TQM barrier is far less than a barrier and more than a success factor in the implementation of TQM in the local context.

Table 1: Rotated factor matrix of the TQM barriers after EFA.

TQM barrier	Factor loading significant at 0.01 level for statement number							Mean	Standard error	Eigen value	Cronbach's α -value
	1	2	3	4	5	6	7				
IHRDM	0.826	0.875	0.772	0.771	0.686			2.04	0.142	3.031	0.830
LL	0.568	0.660	0.758	0.820				1.48	0.112	2.118	0.625
LSQP	0.812	0.704	0.642	0.754	0.508	0.742	0.530	1.80	0.120	3.290	0.788
IR	0.681	0.831	0.808	0.616				2.22	0.133	2.196	0.718
Overall								1.88	0.161		0.893

Moreover, the LL barrier correlated highly and positively with the other barriers (Figure 1). Hence, it can be suggested that the LL barrier is the driver of the other three barriers. A close analysis revealed that if the main driver of successful implementation of TQM, that is, leadership including TM commitment to quality, as considered by many studies (e.g. Demirbag *et al.* 2006), is present properly, then the existence of the three barriers namely IHRDM, LSQP and IR holds minimally. This can be explained by the fact the allocation of resources for areas like quality improvement activities and for employee systematic quality training, which enhances the way employees tackle a quality task/problem, is influenced by TM. Moreover, TM is directly responsible for determining an appropriate organization culture, vision, and quality policy through strategic quality planning (Demirbag *et al.* 2006). Juran (1986) reported that some managers gave SQP a low priority since they are either unable or not willing to plan effectively for quality improvement. However, this present study showed that managers of the responding companies in general practised SQP due to its low mean rating (Table 2).

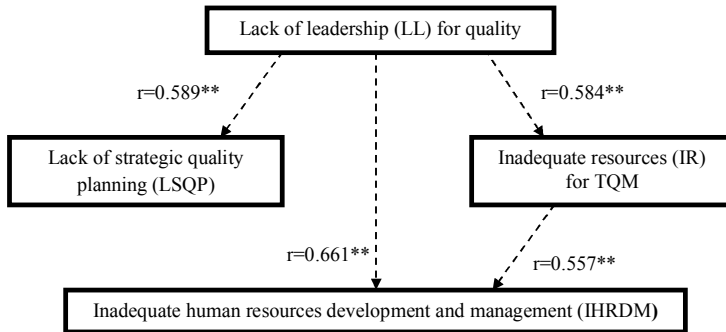


Figure 1: Relationship among TQM barriers investigated in the Mauritian food companies (n=40); correlation significant at * $p < 0.05$, ** $p < 0.01$.

Ranking the mean of each statement in descending order for the three countries indicated that some statements yielded almost the same rank throughout the three countries like L1, S3, S4 and H1 while for some statements, almost the same rank appeared in two of the three countries like S1, S7, R1 and R2 (Table 2). An attempt was made to carry out this comparison due to the fact that the current study dealt with companies only in the manufacturing sector and that conducted by Bhat and Rajashekhar (2009) and by Sebastianelli and Tamimi (2003) focused on 80% and 66% of Indian and USA companies in the manufacturing sector respectively. Hence, an almost similar demographic profile of the respondents, in terms of sector, among the countries enabled the comparison of the mean ratings for similar statements. On comparing the overall mean ratings for the TQM barriers (Table 2) among the three countries, the rating for Mauritius was the lowest and was statistically different ($p < 0.05$) from the other countries. Hence, these barriers had a less impact on the Mauritian companies surveyed as compared to the Indian and USA firms.

Considering the ranks of the individual statements for Mauritius (Table 2), it was found that the statements namely “employees are resistant to change” and “there is frequent turnover of employees” had the highest mean ratings of 2.75 and 2.50 respectively. The Indian firms had a similar problem of employees’ resistance (Table 2). According to Mosadegh Rad (2005), many employees are resistant to TQM because they believe that TQM requires them to work harder for fewer rewards. Moreover, it has been reported in many studies like Mosadegh Rad (2005) that compensation is not always linked to the achievement of quality goals, which explains why many employees are not willing to adopt the new culture that TQM is offering. This explanation could hold true for the current study since most respondents agreed somewhat to the statement (a mean rating of 2.30) that “management’s compensation is not linked to achieving quality goals” and they were thus most probably somewhat resistant to change. However, this monetary obstacle to TQM implementation held the first position in USA firms (Table 2). Lack of benchmarking also ranked among the first ones in USA and India too (Table 2). According to Bhat and Rajashekhar (2009), industries should understand that benchmarking is a tool used to identify their strengths and weaknesses compared to the best in their class. As for the frequent turnover of employees prevailing among the local surveyed companies, a lack of training, lack of a reward system, ineffective employee selection process, ineffective employee compensation and lack of promotion could be some of the causes (Jun *et al.* 2004, Mosadegh Rad 2005).

Table 2: Comparison of importance of barriers to TQM as perceived by Mauritian food manufacturing firms, Indian and US firms

	Statement	Mauritian food manufacturing firms			Indian firms (Sebastianelli and Tamimi 2003)		US firms (Bhat and Rajashekha, 2009)	
		Mean	SE	Rank	Mean	Rank	Mean	Rank
H1	Employees are not trained in problem identification and problems solving techniques.	2.18	0.189	4	2.75	5	3.08	4
H2	Employees are not trained in quality improvement skills.	1.85	0.181	10	2.68	6	3.11	3
H3	Employees are not empowered to implement quality improvement efforts.	1.70	0.169	14	2.30	18	2.86	8
H4	Teams involving all departments are not employed.	1.95	0.182	9	2.51	11	2.27	19
H5	There is frequent turnover of employees.	2.50	0.196	2	2.25	19	2.30	17
L1	Quality is not everyone's responsibility.	1.60	0.192	16	2.31	17	2.28	18
L2	Top management is not committed to quality.	1.20	0.114	20	2.34	15	2.66	10
L3	Quality is treated as a separate initiative.	1.35	0.137	19	2.67	7	2.72	9
L4	There are excess layers of management.	1.75	0.195	11	2.65	8	1.93	20
S1	The best practices and/or products of other companies are not benchmarked.	2.15	0.219	5	3.00	1	3.16	2
S2	Strategic plans do not include quality goals.	1.50	0.156	18	2.55	10	2.40	16
S3	There is no joint planning with suppliers.	1.73	0.160	13	2.48	12	2.61	14
S4	The strategic plan is not customer driven.	1.63	0.185	15	2.37	14	2.63	13
S5	Quality action plans are often vague.	1.53	0.124	17	2.14	20	2.66	10
S6	Quality is not effectively measured.	1.74	0.171	12	2.80	4	2.46	15
S7	Management's compensation is not linked to achieving quality goals.	2.30	0.233	3	2.42	13	3.89	1
R1	Time constraints prohibit effective TQM implementation.	2.03	0.154	7	2.58	9	2.91	6
R2	There are inadequate resources to employ TQM.	2.10	0.182	6	2.82	3	2.95	7
R3	Employees are resistant to change.	2.75	0.217	1	2.92	2	3.02	5
R4	The high costs of implementing TQM outweigh the benefits.	2.00	0.164	8	2.34	15	2.66	10
	Overall mean ratings (ratings with different superscripted letter are significantly different at 5% level)	1.88b			2.54a		2.73a	

4 CONCLUSIONS

Overall, the TQM barriers investigated namely lack of leadership (LL), inadequate human resources development and management (IHRDM), lack of strategic quality planning (LSQP) and inadequate resources (IR) had little relevance in the Mauritian food companies under study as compared to Indian and USA manufacturing firms. This could be because the local companies have adopted generally good practices of TQM. Despite the fact that very few companies have adopted the TQM philosophy in the local food companies surveyed, this study showed that the four proposed barriers to

TQM implementation were not potential barriers in the local context in general. Hence, the local food companies that have not yet implemented TQM seemed to be somewhat ready to start the implementation of the philosophy. As for the statements with highest mean ratings like *employee's resistance to change* and *frequent turnover of employees*, the companies can still try to improve on them.

This study offers a number of implications for managers of medium to large food companies locally. Companies currently implementing TQM, or planning to implement TQM, will pay attention to the barriers for successful implementation of a TQM program. For instance, employees' resistance to TQM implementation can be changed by making them feel that quality helps improve productivity, reduce costs and as Mosadegh Rad (2005) stated, they are directly or indirectly responsible for customer satisfaction. Moreover, according to Jun *et al.* (2004), appraisal schemes such as family finances, basic healthcare facilities, quality and punctuality bonuses can help reduce turnover of employees. Managers should also understand that those barriers vary to different extents in different companies. Hence, managers should understand them well and deal with them accordingly to enable successful TQM implementation. Besides, ranking the different obstacles to TQM implementation can be more useful to develop strategies to improve the success of TQM implementation.

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Sustainability & Renewable Energy

ENVIRONMENTAL IMPACT ASSESSMENT OF THE MANUFACTURING OF A COMMERCIAL AIRCRAFT

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ABSTRACT

This paper documents the methodology and presents the results of a comprehensive LCA study of an Airbus A320 commercial airliner to determine the relative environmental impact of its manufacturing phase. The study was conducted in accordance with ISO 14040/44 using SimaPro LCA software, the EcoInvent inventory database and Eco-Indicator 99 weighting method, which allows the analysis to be outputted in a single score representing a number of damage models including damage to human health, ecosystem quality or resource depletion. Results indicate CFRP wings to have the most significant contribution to the overall environmental impact as a proportion to mass.

Keywords: LCA, Aviation, Airliners.

1 INTRODUCTION

The environmental impact of aviation industry is becoming issue of increased significance, with continued social and regulatory pressure placed on aircraft operators and manufacturers to improve their life cycle emissions. Historically, much focus has been placed on the operation phase of the aircraft and the emissions that result. This is understandable due to the length of service and fuel consumed, however the other stages of an aircraft service life are seldom discussed.

Life Cycle Assessment (LCA) is a powerful technique that can be used to assess the environmental impact of products, processes or services throughout their lifecycle from ‘cradle through to the grave’. In this study LCA has been utilised to study the environmental impact of the manufacturing phase of a passenger aircraft, in order to derive useful conclusions on the major contributors among materials and assemblies, allowing recommendation for further reduction on the environmental footprint. Among the several subassemblies a number of different materials are used, each subassembly will be examined to establish the areas and materials which have the highest environmental impact.

2 LIFE CYCLE ASSESSMENT

LCA provides a useful methodology that can be followed to assess the environmental impact of a process, product or service from design through to disposal using a holistic approach. The LCA process according to International Organisation for Standardisation (ISO) 14040/14044 (BS, 2006a) and (BS, 2006b) consists of four interdependent phases; goal and scope definition, inventory analysis,

impact assessment and finally interpretation of results. Main assumptions, limitations, and system boundaries should be very carefully set in the initial stages of the study, optimizing resources utilization keeping in mind that due to time and data constraints, it is unfeasible to include every process. The plan for conducting the inventory analysis (LCI) is defined in the goal and scope section and consists of collecting all the data required to complete the study. This can include inputs of energy, materials or raw materials and is typically constructed using a flow model diagram. The purpose of the Life cycle Impact Assessment (LCIA) phase is to evaluate the significance of potential environmental impacts based on the results from the life cycle inventory. Impact categories reflect a particular set of environmental issues such as acidification and climate change. For this particular study, the Eco-Indicator 99 characterization model will be used. Although usually LCA is used for assessing the environmental impact of the whole life cycle, it has been also successfully used for assessing the environmental impact of the manufacturing process only as well (Drakopoulos et al., 2009) and (Salonitis, 2012).

3 LCA IN COMMERCIAL JET AIRLINERS

3.1 Goal of the study

This study aims to perform an environmental impact assessment of the manufacturing phase of commercial jets and hence the popular Airbus A320 aircraft, single aisle narrow body, typically operated on short to medium haul routes, has been selected as a case study. The analysis conducted aims to highlight particular components, materials or processes that significantly affect the overall environmental impact of the aircraft. The increased use of advanced materials such as carbon fibre reinforced plastic (CFRP) have assisted in reducing weight and improving fuel consumption, however the emissions created during production and disposal need further examination to determine if the move from more conventional materials represents a positive environmental output.

SimaPro v7.1.8 software (PRE Consultants, 2008) was used to conduct the analysis, together with the EcoInvent v.2 database (EcoInvent, 2007).

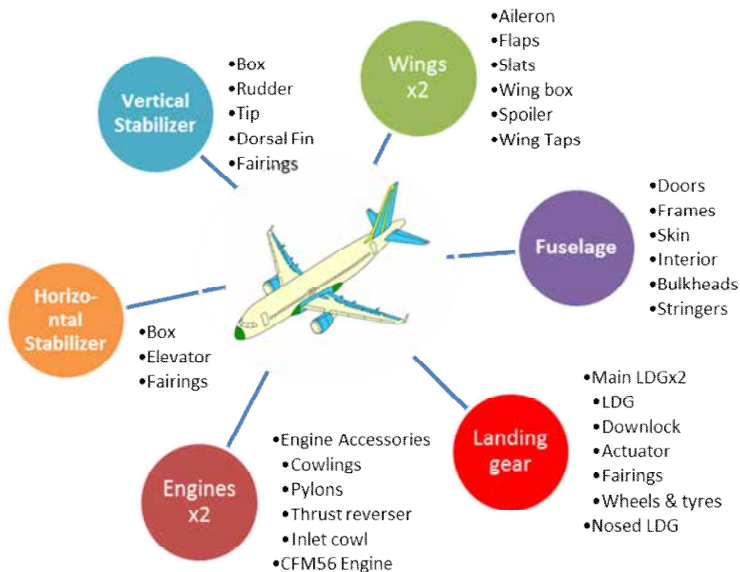


Figure 1: Subassemblies considered for the purposes of the present study

3.2 System Boundaries and Limitations

This study considers the complete life of an aircraft over a 20-year service life. The LCA was modelled in second order, ignoring capital goods involved during production. An average large commercial aircraft will consist of millions of parts and components (Scott, 2009), which would be unfeasible to model due to time and data constraints. Therefore the A320 has been separated into major structural components which can be divided into separate sub-assemblies. For the purpose of this study, 6 assemblies and 75 sub-assemblies have been considered (figure 1). The major structural components of the A320 are manufactured in several plants located European wide and then transported to the final assembly line in Toulouse, France. Transportation, excluding the engines, has been considered in the overall LCA, with average distances calculated from each manufacturing base to Toulouse. Disposal was also included for the aircraft involving recycling, incineration and landfill, data of which is discussed in the following sections.

Limitations of the study constitute the fact that aircraft systems and internal components have not been considered as they are often manufactured by third parties thus limiting the availability of accurate data. Manufacturing processes involved in the production of the A320 may also vary from the processes established in the Ecoinvent database. However methods continually evolve, with processes today varying from those during the infancy of the A320.

3.3 Life Cycle Inventory Analysis

The sub-assemblies of the A320 consist of a number of different materials and corresponding masses. With the scarcity of data containing precise mass and material compositions, a number of educated assumptions had to be made. The Operational Empty Weight (OEW) of the A320 is 41,244kg (Airbus, 2005), which includes the weight of the structure, power plant, furnishing, systems and all other operators' items such as life vests and engine oil. All systems aboard the A320 have been neglected from the study and have been assumed to account for 10% of the overall OEW. Each CFM56-5B engine has a basic dry weight of 2,380kg therefore the structural mass excluding engines is 34,420 kg. Table 1 summarises the assumptions relating to the mass of each assembly while Table 2 includes the proportional content of each major material in the A320 structure.

Table 1: Assembly masses used in study

A320 Assembly	Total Assembly Mass (kg)
Wings (x2)	13713
Fuselage	11755
CFM56-5B (x2)	7052
Main Landing Gear	3918
Horizontal Stabiliser	1175
Vertical Stabiliser	1175
Nose Landing Gear	392
Total	39,181

Table 2: Material composition data for the A320, excluding engines

Structural Material	Percentage Composition	Approximate Mass (kg)
Aluminium	68%	23,405
Composites	15%	5163
Steel	9%	3098
Titanium	6%	2065
Miscellaneous	2%	689
Total		34,420

(Rendigs and Knuwer, 2010)

Composite materials are expected to be the most important for this analysis due to the fact that they are more energy intensive to manufacture and with challenges relating to disposal (Suzuki, 2005), therefore their LCA impact during production is expected to be significant. The major composite constituent is CFRP, of which the content in each assembly has been modelled based on data available (Airbus, 2005), and accounts for 99% (1163 kg) of the horizontal stabilizer, 96% (1128 kg) of the vertical one, 9% of the engines (635kg), 8% (1097kg) of the wings and 7% (82 kg) of the fuselage (Figure 2).

Material profiles for CFRP are not currently available in any LCI databases. Therefore a custom entry was modelled, data for which were obtained from (Duflo, 2009) and (Suzuki, 2005).

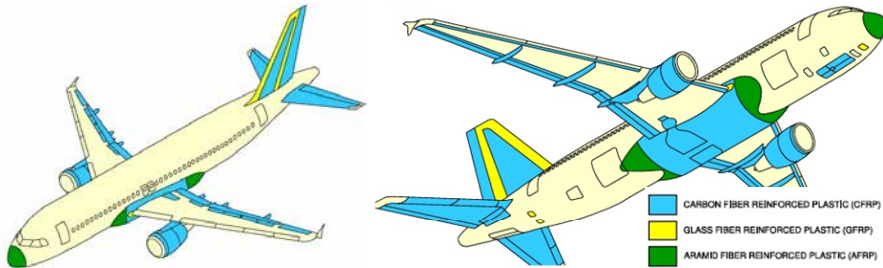


Figure 2: Location of composite materials on External Surfaces of A320 (Airbus, 2005)

As previously mentioned the assemblies of the A320 are manufactured at separate locations and transported to the Final Assembly Line (FAL) in Toulouse. Manufacturing locations are split across several European countries, with differing methods of transport used. The transportation of each sub-assembly has been considered from production to final assembly. The total estimated transportation used to relocate all assemblies and sub-assemblies to the FAL has been calculated to 1.67×10^4 tn.km via airfreight and 1.37×10^4 tn.km via road transport.

4 RESULTS AND DISCUSSION

Manufacturing has been shown to represent a small impact in the overall lifecycle (Howe et al., 2013), however manufacturing phase is significant and will be examined in more detail. The modelling of the manufacturing phase has been conducted using the Eco-Indicator 99 (H) method, which aggregates each process impact into a single score.

Carbon dioxide (CO_2) emissions is of particular interest to manufacturers operating within the European Union, due to regulatory obligations under the EU emissions trading system (ETS). The ETS scheme provides annual 'carbon credits' to all emitting companies, with those exceeding their allowance having to purchase additional credits. The overall impact of each assembly over the manufacturing phase is displayed in Figure 3, with the CO_2 emission proportions also displayed. It can be observed that the wing assembly and engines have the highest environmental impacts and together represent nearly two thirds of the total emission score. The impact compares similarly to the mass of the wing (35% of total mass) with a 32% impact. However, the fuselage although similar in mass to the wing is significantly lower with a 19.3% total impact contribution. The horizontal stabilizer assembly also shows a similar trend to that of the wing.

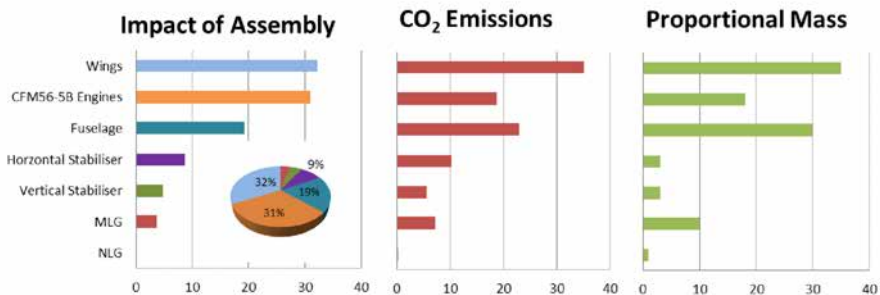


Figure 3: CO_2 Emitted (estimated using Eco-indicator 99 (H), Category Climate Change), Total Impact (%) and Proportional Mass (in kg) per Assembly

The overriding factor for this increase in environmental impact is the choice of material. The use of CFRP represents almost half of the total process contribution (45.4%) compared to only 18.4% for aluminium alloy, despite aluminium representing nearly 70% of the total material content. Assemblies such as the fuselage which are predominately aluminium have a relatively low impact to mass proportion. However assemblies using higher levels of composite material such as the horizontal stabilizer show the opposite trend with the total impact significantly higher than the proportional mass. The impact of the power plant assembly is one of the highest environmental contributors, despite being almost half the mass of the wing assembly. This can again be attributed to the high levels of CFRP, titanium and nickel when compared to aluminium.

To better quantify the overall impact of composite parts in the manufacturing lifecycle all CFRP was replaced with its aluminium. CFRP is predominately used in aircraft manufacturing due to significant weight reductions of more than 25% (Achternbosch et. Al., 2002). Therefore the alternative A320 model without CFRP has been modelled as 30% heavier to standardise the results. Figure 4, illustrates the impact of CFRP, when used instead of conventional materials, converting all the LCI data into a single score for each impact factor. The environmental significance of CFRP is highlighted by the vertical and horizontal stabilizer assemblies; both conventionally contain over 90% composite material; however the replacement to aluminium improves the environmental efficiency of both by over 80%.

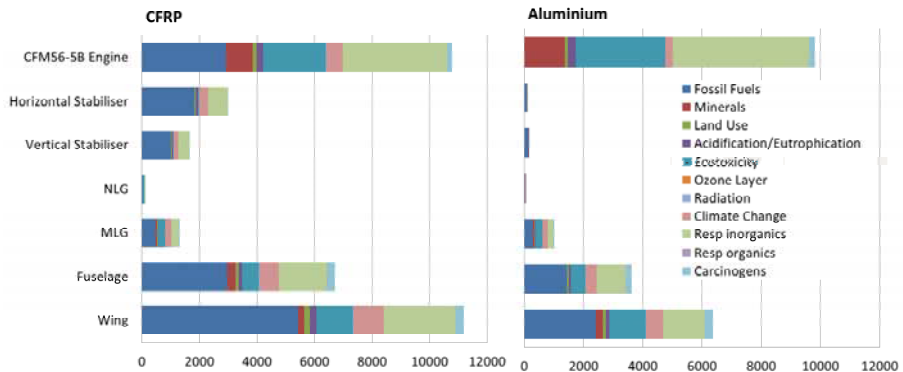


Figure 4: Comparison between an actual A320 and A320 without CFRP (Weighting, Single Score)

Classification, characterisation, normalisation and weighting are key steps of life cycle impact assessment aiming to represent in a single score a series of environmental impacts representing endpoints. In this study the Eco-Indicator 99 method has been employed. Figure 5 presents normalised results for the Eco-Indicator categories of the manufacturing phase of the A320 relating to the impact categories. Fossil fuel depletion is the most significant contributor to the overall impact followed by respiratory inorganics, with wings and engine component to contribute more to the impact of the assembly.

5 CONCLUSIONS

This paper examined the environmental performance of the manufacturing phase of a commercial passenger jet predominantly based on masses of materials and basic processes. Results show that fabrication of CFRP components have the greatest impact to the overall results illustrating that although this material allows mass optimization, the same trend is not followed for environmental impact. In the scarcity of relevant studies, this paper illustrates the need for more analytical analysis of the manufacturing process also taking into account further aspects of the prefabrication and assembly of components.

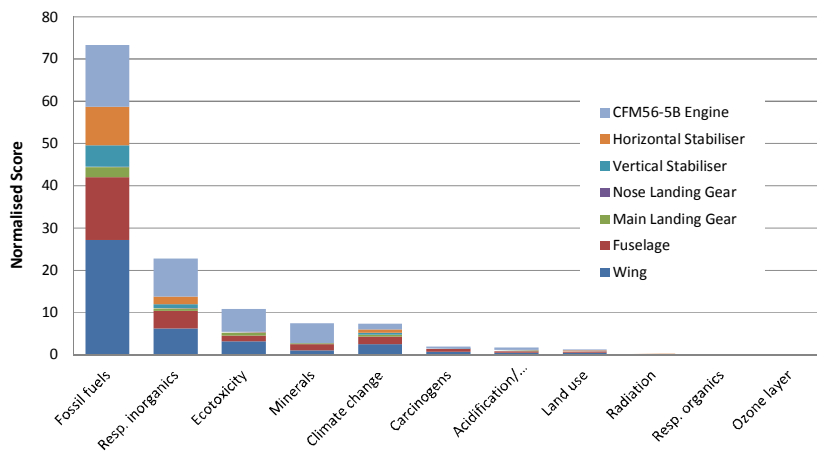


Figure 5: Normalised results for the Eco-Indicator categories of the manufacturing phase of the A320 relating to the impact categories

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TOWARDS A BUSINESS MODEL FOR SUSTAINABLE SUPPLY CHAIN MANAGEMENT

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ABSTRACT

Designers make decisions that ultimately impact on both the economic, environmental and social performance of the products and process, and many of these costs and impacts occur across the supply chain. This paper aims to show initial elements of a research which aims to develop an integrated business model for sustainable supply chain management in order to facilitate the business management process in terms of assessment of suppliers and collaboration addressed to the sustainable improvements across supply chain. It is noteworthy that it is an imperative in the current competitive market that companies must be able to manage their entire production chain taking into account sustainable issues as an important factor in their decision processes. Therefore, it is believed that this model can integrate and strengthen a company's functions and assist its decision processes as well as implement improvements within its supply chain.

Keywords: sustainable supply chain, business model, environmental management.

1 INTRODUCTION

Businesses have been challenged to recognise that the ecological footprint of their products and services is not limited to the production stage of the final product manufacturer (Nawrocka *et al.* 2009). In fact, all stages of the product lifecycle influence on the environmental burden of a supply chain, including resource extraction, manufacturing, use, reuse, recycling or final disposal (Zhu *et al.* 2007).

According to Hervani *et al.* (2005), the responsibility of the company now spreads over a number of actors along the supply chain. As a consequence, many companies have developed sustainable practices for a huge number of actors along the supply chain (Schmidt and Schwegler 2008) which are not only located downstream but also upstream, including companies responsible for product delivery, and have a reverse logistics system addressed to product recovery or sound final destination (Srivastava 2007).

Sustainable supply chain management (SSCM) practices have emerged in this context. According to Hakke and Seuring (2009), SSCM is a set of actions and relationships in terms of design, procurement, production, distribution, use, reuse and disposal of the firm's goods and services in response to concerns for the environment and social issues. In addition, Seuring and Muller (2008) define SSCM as the management of material, information and capital flow, as well as cooperation among companies along the supply chain, while meeting sustainable goals and taking into account customer and stakeholder requirements.

Both environmental aspects and corporate social responsibility (Gimenez and Tachizawa 2012) are involved in SSCM practices. Social practices have been carried out by focal companies (FCs), which are the most influential organisations in the production chain due to their purchasing power, their direct contact with customers and their influence on adoption of the sustainable standards and features by other members of the supply chain. The most common social practices implemented by FCs are: implementation of supplier code of conduct, market governance mechanisms addressed for extensive collaboration, social management system – SA 8000 (Social Accountability), ISO 26000,

sustainable report (such as Global Report), social audit addressed to check labour conditions or slave and child labour practices and connectedness within and outside the community and quality of life.

However, FCs have focused more on their environmental practices than social as part of their SSCM practices (Hervani et al 2005; Srivastava 2007; Seuring and Muller 2008; Testa and Iraldo 2010; Despeisse et al. 2012; Gimenez and Tachizawa 2012; Ahi and Searcy 2013). This can be justified by driving forces which generally involve more environmental than social issues. For example, the sustainable standards demanded by government are more related to the environmental aspects, such as the restriction of the use of certain hazardous substances in electrical and electronic equipment established by the RoHS Directive 2002/95, eco-design for energy-using products (Directive 2005/32/EC), the take back obligation for electrical and electronic equipment waste (Directive 2002/96) and registration, evaluation and restriction of chemicals (Directive 1907/2006) (Ongondo *et al.* 2009; Wang and Gupta 2011). Consequently, the adoption of selection criteria and assessment of suppliers in purchasing, product performance assessment and improvements (Life Cycle Assessment and Ecodesign) are being increasingly implemented by focal companies. Focal firms can have problems if they do not manage their suppliers in terms of environmental compliance. A specific example is the recall carried out by Mattel in 2007. A total of 20 million children's toys were recalled due to materials found to contain traces of lead used by some suppliers.

In addition, according to Roberts (2003), a non-governmental organisation (NGO) can influence the reputation of the focal company, demanding responsibilities in the upstream and downstream production. For example, Nike, Disney, Levi Strauss, Benetton, Adidas and C&A in recent years have been criticised for problems such as environmental contamination that occurred in their suppliers' production stages (Seuring and Muller 2008).

To sum up, image, reputation, and standards demanded by NGO's, customers, shareholders, governments, or even competitors are all considered major external motivations to a focal company which has adopted SSCM practices. On the other hand, promoting competitiveness in the chain, reducing costs and pressure from workers are examples of internal driving forces for SSCM (Haes and Rooijen 2005; Seuring and Muller 2008; Jabbour and Jabbour 2009).

Therefore, it is imperative in the current competitive market that companies manage their entire production chain, considering environmental and social issues to be important factors in the decision-making process. Thus, this paper aims to show initial elements of a research which aims to develop an integrated business model for sustainable supply chain management in order to facilitate the business management process in terms of assessment of suppliers and collaboration addressed to the sustainable improvements across supply chain.

This research has been conducted in collaboration with the EPSRC Centre for Innovative Manufacturing in Industrial Sustainability. The centre has outlined a number of Grand Challenges for a number of PhD students to research under; namely, Eco-efficiency, Eco-Factory and Sustainable Industrial Systems. This work will contribute towards the Sustainable Industrial System, which aims to "help companies to explore future configurations of the industrial system, and their implications, and take first step to improve understanding of the long term challenges facing industry". This proposal is sponsored by the Brazilian government through the programme "Science without Borders". The main goal of this programme is to promote the consolidation and expansion of science, technology and innovation in Brazil by means of international exchange and mobility.

2 RESEARCH PROGRAMME

2.1 Research Questions and Objectives

- **R.Q.1.** What are the current practices (approaches, tactics, tools, strategies) in supply chain management for sustainable improvements?
- **R.Q.2.** What are the driving forces and drawbacks to adoption of SSCM practices and their impacts on business management process?
- **R.Q.3.** How can members of an entire supply chain be assessed in terms of the effectiveness of environmental management (practices and performance) and corporate social responsibility (practices) and what data is needed to make the assessment and what is not?

- **R.Q.4.** How to develop collaborative relationships with members of an entire supply chain to achieve sustainable improvements?

Table 1: Objectives of proposal

Objectives	Description	Derived from
O.1	To understand the relationship between members of the entire supply chain and focal company in terms of adoption of sustainable practices, drive forces and drawbacks.	R.Q.1 & R.Q.2
O.2	To analyse and classify the SSCM practices to design the conceptual model to assess members of an entire supply chain	R.Q. 3
O.3	To understand the types of collaboration addressed to sustainability across an entire supply chain, and to analyse and classify them to design the conceptual model to give support to member to improve their sustainable stance	R.Q. 4

2.2 Research approach

a) Phase 1 - Analysis of the "state of the art"

A systematic literature review will be conducted to analyse the "state of the art" sustainable supply chain which will take into account the entire supply chain, both environmental and social elements of SSCM, and sustainable approaches for the supply chain.

Interestingly, a systematic review is a specific methodology that allocates existing studies, selects and evaluates contributions and reports on the evidence from a specified question (Denyer and Tranfield 2009).

This systematic review (A.1.1) will be guided by research questions R.Q.1 and R.Q.2 and conducted by steps described below, which are based on Seuring and Muller (2008), Denyer and Tranfield (2009) and Gimenez and Tachizawa (2012).

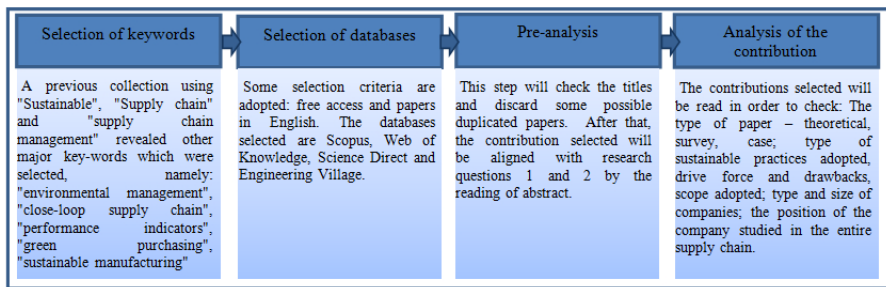


Figure 1: Steps of a Systematic review

Furthermore, interviews will be conducted with research experts (from Cranfield University and Centre for Innovative Manufacturing in Industrial Sustainability, and other universities) and expert practitioners (from, for example, Toyota and Unilever) (A.1.2). This phase also includes initial visits to the "focal company" (that needs to be selected and contacted for developing this proposal) in order to recognise its sustainable practices and mapping of its extended supply chain. For this reason, based on previous activities, a survey form will be designed to guide the initial data collection (A.1.3).

The activities A.1.2 and A.1.3 will explore the real sustainable practices (tools/tactics/strategies/approaches) which have been used by industries in terms of supply chain management.

Therefore, the literature will be critically reviewed in order to identify more gaps in research. Also, reported practice will be analysed to understand if these gaps have been addressed in industry. The stage seeks to understand the relationship between sustainable approaches in supply chain

management which have been developed by academics and their real implementation across the companies.

b) Phase 2 – Model Development and Refinement

This stage is guided by R.Q.3 and R.Q.4. Also, the model will be designed to take into account the results of activities 1, 2 and 3. The essence of the model will be addressed to the assessment and collaboration with suppliers in terms of sustainable improvements.

It is intended in this stage to refine the model (A.2.2) through contact with managers of the focal company and its suppliers to identify possible improvements and adaptations of the model.

It is expected that the outputs from this phase will be submitted to conferences (such as Global Conference on Sustainable Manufacturing, International Conference on Sustainable Intelligent Manufacturing, International Conference on Industrial Engineering and Operations Management) and journals (e.g. Journal of Cleaner Production, Journal of Supply Chain Management; European Journal of Operational Research) are expected. Therefore, other researchers and practitioners could comment on the model proposed and that can be included in the refinement.

c) Phase 3 – Model application and validation

This phase is guided by R.Q.5 and is aimed at the application of the model (A.3.1) and model validation. Thus, the model will be applied and its outcomes will be interpreted, analysed and discussed, including aspects like benefits and limitation of the model.

To process the model validation (A.3.2), submissions are expected both to journals and conferences in order to receive feedback from researchers and practitioners. In addition, a final workshop will be held with managers who are involved and members of the Industrial Sustainability Centre.

3 DELIVERABLES

It is expected the development of a business model, which will take into account some possible elements in the design process, such as:

- Limits and scope (selection of a product and selections of member of entire supply chain);
- Variables that should be addressed in this study (social and environmental variables);
- The development of a classification system of sustainable maturity level of members of an entire supply chain;
- The development of modelling to calculate environmental performance of the member of the supply chain (which will include the definition of indicators, data collection, validation, simulation and definition of the burden of suppliers);
- The design of a system to support the decision-making process and collaboration with suppliers to improvements related to environmental management and corporate social responsibility.

This model can be used by focal companies in order to measure their supply chain in terms of environmental performance and tactics adopted as well as social tools adopted. Thus, it will be possible to assess the level of maturity of member of an entire supply chain and develop partnership with suppliers in order to improve the sustainable stance of supply chain. Therefore, this research can lead the organisation to further sustainable manufacturing position, strengthening members of supply chain partnership, supporting sustainable improvements and the decision process in organisations.

Figure 2 illustrates some principles of the model: the scope and type of interaction with suppliers. The scope will take into account the entire supply chain including upstream and downstream interaction. In addition, not only environmental aspects (performance and practices adopted) but also social aspects (practices adopted) will be considered in the type of interaction.

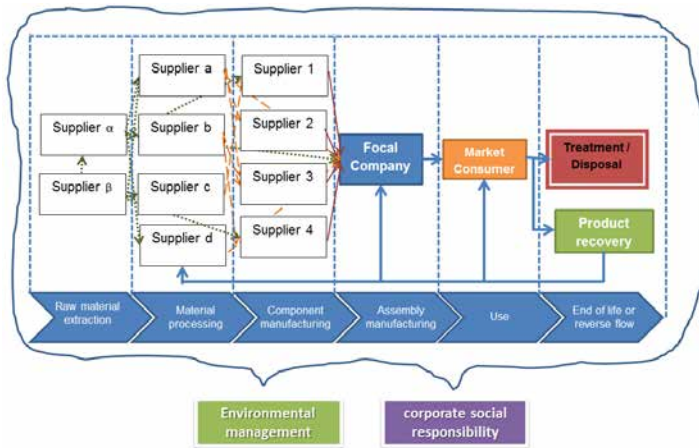


Figure 2: Principles of the business model of sustainable supply chain management

The analysis of the literature revealed some gaps related to sustainable supply chain management in terms of the type and the scope of the interaction between a focal company and members of the entire supply chain. The type of interactions is related to the practices used by FCs to analyse and improve sustainable issues across the supply chain. The scope in turn means where (upstream / downstream) and which member are involved by SSCM practices adopted by FCs.

The concept of sustainable supply chain management encompasses the entire lifecycle perspective, i.e., raw material extraction, pre-manufacturing (material processing and components manufacturing), manufacturing, market, and final destination or recovery of product as well as the transportation between these steps. Interestingly, it was seen in the literature that many companies have just focused on upstream flow. Focal companies have extended sustainable criteria for first-tier suppliers. This is generally conducted by an assessment of sustainable standards demanded during purchasing, such as eco-labeling of materials/products, management systems certificated (ISO 14001, SA 8000), sustainable reports, etc.

It was observed that many focal firms have carried out Life Cycle Assessment (LCA) in an attempt to evaluate the environmental impact of a product across its entire lifecycle. However, it cannot point out how each member of the supply chain contributes to the environmental burden of the product assessed. In addition, the complexity of conducting an LCA in terms of money, time and data collection effort can be considered a limitation for its full implementation (including all steps of life cycle).

In terms of the type of interaction with suppliers, the first practice is already mentioned; assessment of suppliers. This approach by itself does not guarantee a good sustainable performance or contributes to increasing suppliers' sustainable commitment. Basically, this assessment might sort a firm if it has a minimal sustainable stance to be a supplier. According to Gimenez and Tachizawa (2012), firms need to engage in collaborative practices in order to improve the sustainable stance of their suppliers. In addition, collaboration includes direct engagement between the various levels of the supply chain, in which the focal company commits itself to the improvement of its suppliers (Simpson and Power, 2005). Assessment may be the first step to identify what actions are needed. Therefore, despite the growth in sustainable supply chain research, it is difficult to find out how to evaluate members of an entire chain as well as to use this information to support sustainable improvements in the production chain.

4 CONCLUDING REMARKS

This article discusses the potential application of environmental management and social responsibility across the supply chain. This research will have as deliverables the development of a validation

process for sustainable strategies and a mapping of environmental along extended supply chain; it includes the presentation of elements that can help companies to promote changes within the chain contemplating a more environmentally friendly view, creating conditions for meeting sustainable stance.

We believe that this research can encourage the organisation to further sustainable actions, strengthen supply chains, support environmental life cycle management of products, and improve the decision processes in the organisations. In this context, this research looks to bridge the gap in the sustainable supply chain management in terms of assessment and collaboration with suppliers. This research also takes into account the entire supply chain and includes the environmental burden of members, sustainable tools, tactics and models implemented and a system to help focal firms focus on sustainable improvements across the production chain.

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A FRAMEWORK OF INDUSTRIAL SUSTAINABILITY GOOD PRACTICES

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ABSTRACT

Global environmental problems, energy and raw material prices as well as their availability, increasingly demanding legislation and environmental taxes are some of the reasons that drive the consideration of sustainability concepts and practices into company operations. This paper presents the research carried out in order to capture industrial sustainability good practices and represent them into a framework to help companies increase their awareness and adopt practices to embed them within their operational processes.

Keywords: Sustainability, Industrial Framework, Best Practices.

1. INTRODUCTION

Climate change, the unbalanced use of natural resources, extinction of many animal species caused by emissions and waste are results of unsustainable practices of consumption and production. This is a real threat to the global environment as well as to welfare. Traditionally, businesses were exclusively focused on generating revenue, not considering the impact of their activities on the environment. Adopting, sharing and continuously improving sustainability practices are the solutions to gain competitive advantages from environmental, economic and social points of view. This paper presents the research work undertaken to develop a framework of sustainability good practices with the aim to make such practices available in order to embed them within operational processes. This would reinforce commitment in supporting the global environment while maintaining their competitive advantage.

The research followed the methodology of three main phases as follows:

- 1) Synthesis of the good practices through intensive literature review
- 2) Performing industrial field studies by conducting face-to-face or telephone interviews
- 3) Development of a sustainability good practice framework.

2. IDENTIFICATION OF SUSTAINABILITY GOOD PRACTICES IN THE LITERATURE

Sustainable development is defined as 'the development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland 1987). The main three pillars for sustainable development are economic prosperity, environmental quality and social equity, which need to be pursued simultaneously. 90 sustainability good practices were captured from the literature which are guidelines for this industrial field study. These are energy management,

community involvement, workforce culture, direct productivity enhancement, supply chain management, standards and regulations, decision tools as well as waste minimisation, and pollution prevention. Kutz (2007) presented many good practices regarding electrical power, combustion systems, thermal systems, motor systems, and maintenance and equipment control. Wang et al. (2006) focused their research on the categories of good practices related to the area of waste minimisation and pollution prevention, such as alternative fuels, abatement systems and waste treatments. In contrast, Beaufort-Jones et al. (2008) researched fuel generation from waste, water use and treatment, equipment control, alternative energy sources, and specially lighting, facility design and workforce culture. Other sources employed for the sustainability good practices synthesis were Ecocycle (2000), Rehan and Nehdi (2005) and the European Environmental Agency (2008).

3. SEMI-STRUCTURED SUSTAINABILITY QUESTIONNAIRE

A semi-structured questionnaire had been developed using the results of the literature review. Further information was collected from the ten participating companies' (Table 1) websites and published reports focusing on Environmental Health and Safety (EHS) and corporate reports.

Table 1: Industrial collaborators.

Company	Data collection method
Caltec - Service provider for the oil and gas industry	<ul style="list-style-type: none"> • Face-to-face interview - Technical Director • Information from the company website
British Waterways - Managing canals and rivers	<ul style="list-style-type: none"> • Face-to-face interviews - environmental scientists and managers • Information from the company website and documentation
Xerox - Document management	<ul style="list-style-type: none"> • Face-to-face interview - Design Manager
Aerospace	<ul style="list-style-type: none"> • Observation
Metsec - Cold roll-forming	<ul style="list-style-type: none"> • Face-to-face interview - Quality Manager
GlaxoSmithKline - Pharmaceutical	<ul style="list-style-type: none"> • Telephone interview - Environmental H&S Product Stewardship member • Information from the company website
Edwards vacuum - Vacuum and exhaust management equipment	<ul style="list-style-type: none"> • Telephone interview - Quality Manager • Information from the company website
BHR Group - Research and consultancy	<ul style="list-style-type: none"> • Face to face interview - Senior Project and Engineering Manager • Information from the company website
Analytical instruments manufacturer	<ul style="list-style-type: none"> • Face to face interview - Senior engineer responsible for the new environmental initiative
CEMEX - Cement producer	<ul style="list-style-type: none"> • Face to face interviews - senior and middle managers • Visits to two production plants in Spain and the UK

The authors customised the questionnaire to suit different large companies. It was divided into the following key areas:

- 1) Energy Efficiency
- 2) Emissions, Waste and Wastewater Management
- 3) Standards / Legislation
- 4) General Enterprise Sustainability Practices
- 5) Health and Safety
- 6) Product Design Engineering and Development
- 7) Manufacturing Engineering.

An example question is the following:

“Do you reuse the residual heat from the processes (to produce steam, preheat combustion air, heat the plant, etc)?”

Also, details about the specific practices detected in the company were enquired as the example shows:

“How do you reuse waste from the internal processes? The Company information stated that Waste-Free factory policy has increased the recycling rates by 90%; can you provide any specific measure that helped to obtain those results?”

The company reports were also a source of good practices used for the generation of the sustainability framework illustrated in Figure 2. As the next step six face-to-face and three telephone interviews took place with four visits to the manufacturing or test facilities.

4. A FRAMEWORK OF INDUSTRIAL SUSTAINABILITY GOOD PRACTICES

The sustainability good practice framework was generated from the data acquired in the industrial field studies, and it consists of nine main sustainability areas which are the following:

- **Energy Efficiency:** represents one third of the sustainability good practices acquired and consists of machinery/processes, facilities, heat use/recovery, and organisational initiatives;
- **Emissions, Waste and Wastewater:** how to reduce, re-use and recycle internal wastes. In addition, examples of the use of recycled materials and external waste, initiatives to reduce water consumption, and initiatives on how to reduce and control waste, were also captured. An examples is developing a guide/workbook for waste reduction and recycling; Decision Tools and Improvement Programmes: includes approaches to implement decision/assessment tools such as LCA and EIA or managerial initiatives: using lean six-sigma programmes to increase energy efficiency;
- **Decision Tools and Improvement Programmes:** In this area, examples of improvement programmes regarding sustainability issues are provided as well as approaches to implement decision/assessment tools such as LCA and EIA. For example: 1) Using lean six-sigma programmes to increase energy efficiency, 2) Developing a web-based system to share cost saving and environmental improvement ideas among the geographically distributed companies;
- **Standards, Legislation and Regulators:** these practices describe ways to deal with regulators and fulfil standards so that the company improves its sustainability performance. One good practice that was captured is implementing cleaner technologies which lead to receiving incentives and recognition from the government as well as addressing the social and environmental issues at lower cost;
- **Health and Safety:** tools, assessments, management of initiatives and programmes to improve the health and safety of the employees. An example is a system available for employees to report any hazard related to work. As soon as a hazard is reported an engineer is assigned to address and solve the hazard within 30 days; if this does not happen, then it is considered a negative result against the site. The ‘lead safe programme,’ where staff is asked to upload onto the intranet at least one proactive measure a month regarding safety and environmental improvements. This is then to be shared by all. Implement internal guidelines and policies in the production sites to use proper equipment. Motivate its employees to eat healthy, sleep well and do exercise at least twice a week;
- **Supply Chain Management:** to reduce the impact of the company along the whole supply chain: the re-use of containers with the suppliers, or provide company’s expertise regarding energy efficiency to the suppliers;
- **Community Involvement:** initiatives with schools, universities, etc.: a company having its laboratories in a university in order to have mutual benefits in terms of cost, use of the facilities and generation of knowledge through the use of the lab by research students, as well as providing future human resources to the companies with the right skills. General Business Practices represent the corporate good practices that did not fit in the previously described areas, Formal meetings performed twice a year with information sharing purposes, involving key people from the environmental/sustainability area of the site and their equivalents in other business units, Creating an ‘Environmental Advisory Board’ to review the current practices and provide practical recommendations. The members of such a board are invited from universities, research and development centres, environment agencies, local government, etc.;
- **Product Development:** embedding sustainability in the product development stage: sustainability and environmental toll gates. The applications of design for X where X could stand for environment, re-use, recycling, services and safety, and Sustainability and environmental toll gates

to ensure the detail consideration of these issues during product development including the less use of material and energy.

This stage of the research has captured around 157 sustainable good practices. Only 25% of the captured good practices were obtained from the published reports, the remaining from the interviews. The distribution of good practices can be seen in Figure 1.

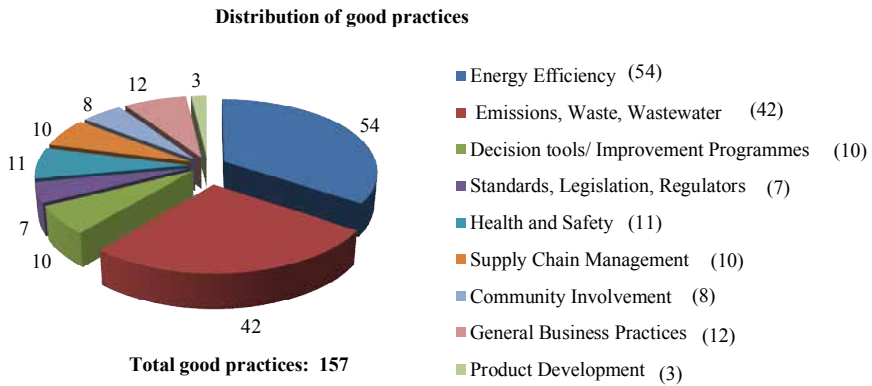


Figure 1: The distribution of the good practices among the nine main sustainable areas.

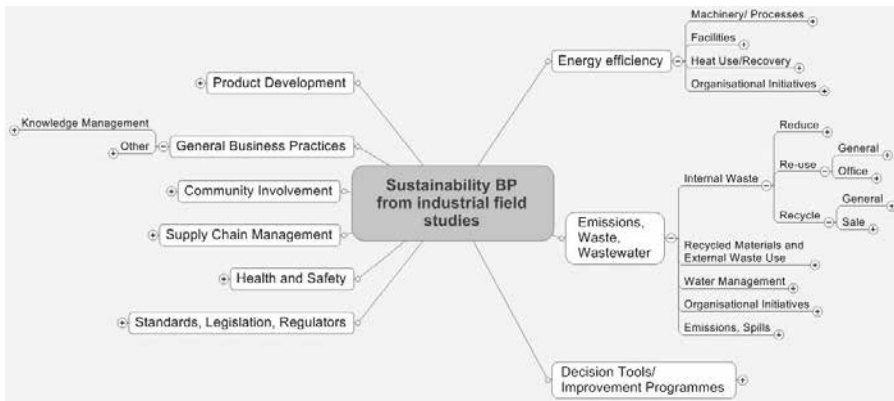


Figure 2: Sustainability good practices Framework - 1st and 2nd layers.

More than half of the sustainability good practices aimed at two areas: ‘Energy Efficiency’ and ‘Emissions, Waste and Wastewater management’. This clearly shows the attention that the industry is paying to the areas that have a major impact on the environment. A graphical representation of the framework is shown below as layers 1 and 2 (Figure 2) and as layer 3 and 4 (Figure 3) from the “Energy Efficiency” area. The first layer shows the name of the library and the nine main areas of good practices, the second layer the sub-topic structure of good practices inside each main area, the third layer relates to the Sustainability good practices titles and the corresponding brief explanation, and the fourth layer gives detailed examples of the good practices as employed by the company. The form could be text note, PDF file, table, photos.

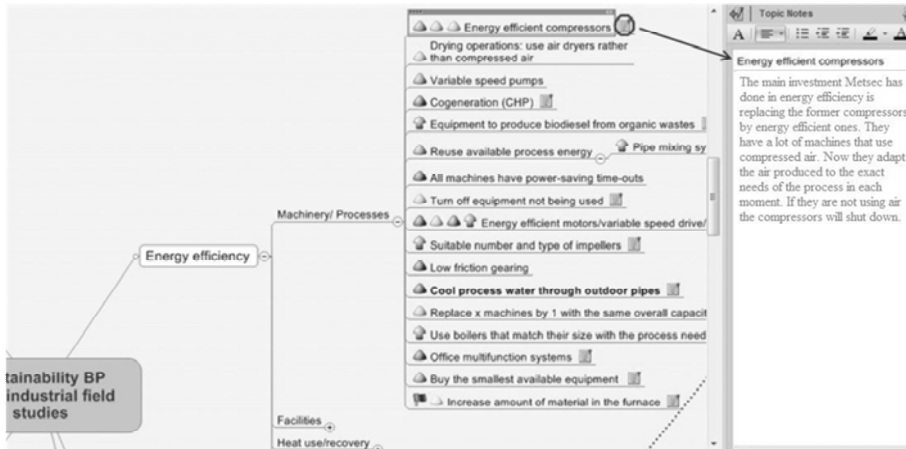


Figure 3: Snapshot of layer 3 and 4 from the “Energy Efficiency” area.

5. CONCLUSIONS AND FUTURE PLAN

Findings of this research show that the included industries pay a great attention to sustainability issues. The study shows that the implementation of the sustainability good practices is an on-going issue in many companies. Companies lack an efficient system for managing sustainability good practices within the business. The presented cross-sector sustainability good practices framework is a tool with potential use across all industry. The questionnaires developed in this project can be employed as a base for conducting more industrial field studies. Future plan is to involve acquiring and generating quantitative data regarding the good practices implementation in order to add value to the presented work.

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INDUSTRIAL WASTE MANAGEMENT WITHIN MANUFACTURING: A COMPARITIVE STUDY OF TOOLS, POLICIES, VISIONS AND CONCEPTS

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ABSTRACT

Industrial waste is a key factor when assessing the sustainability of a manufacturing process or company. A multitude of visions, concepts, tools, and policies are used both academically and industrially to improve the environmental effect of manufacturing; a majority of these approaches have a direct bearing on industrial waste. The identified approaches have in this paper been categorised according to application area, goals, organisational entity, life cycle phase, and waste hierarchy stage; the approaches have also been assessed according to academic prevalence, semantic aspects, and overlaps. In many cases the waste management approaches have similar goals and approaches, which cause confusion and disorientation for companies aiming to synthesise their management systems to fit their waste management strategy. Thus, a study was performed on how waste management approaches can be integrated to reach the vision of zero waste in manufacturing.

Keywords: waste management, industrial waste, manufacturing

1 INTRODUCTION

An increase in global manufacturing activities is evident. Globalisation, industrialisation, and economic development has led to an increase in product demand and increased manufacturing activity – we have seen a 35% increase of global manufacturing activities over 2001-2010 while the global GDP increased by 26% (Wiktorsson, 2012), which also lead to larger volumes of industrial (material) waste (Tojo, 2004). Since the introduction of the concept “sustainable development” (WCED, 1987) and commitment to the United Nations Commission on Sustainable Development (EU, 1987), the apprehension of limited resources on the earth has been noticed remarkably (Tojo, 2004).

In the last 20 years, industrial waste has become a critical issue and causes concerns with regards to global sustainability and environmental effects (Macarthur, 2012). In 2010, the total generated waste from households and economic activities in the EU-27 amounted to 2 570 million tonnes while Germany, France and UK have the most portion in the generated waste. Manufacturing accounted for 280 million tonnes of waste generation in 2010 (around 10.9 % of the total) while generated waste from households accounted for 221 million tonnes in the EU-27. UK, Poland, Italy, Germany and France together generated around 60% of total manufacturing waste in 2010, whereas UK produced around 23 million tonne (8% of total manufacturing waste) and Sweden produced 7.8 million tonne manufacturing waste (2.7 % of total manufacturing waste). However, waste quantity is one problem while the quality of waste is the other – being hazardous or non-hazardous, valuable or non-valuable. Current industrial waste management challenge is to keep high quality grades of material in the industrial system.

The scope of waste management is wide and encompass different terms. Both industrial waste and depletion of virgin material put pressure on manufacturing companies to find new viable approaches

that are in line with environmental, social, and economical sustainability. Different approaches have been created in academia and industry in the past few years, but evidence of actual use of them is not clear. They also overlap each other by having similar goals and proposing similar approaches toward waste management (Lilja, 2009). Examples of such concepts are zero waste, waste minimisation, zero emission and waste prevention. To support conquering of mentioned challenges, this paper contributes to the field of sustainable manufacturing by presenting a comparison of tools, policies, visions and concepts for industrial waste management.

2 RESEARCH DESIGN

A structured literature search was done as complement to former reviews on waste management approaches that are applicable for manufacturing industry. Of the identified papers addressing industrial waste management, 80 papers were reviewed to identify and contrast different waste management approaches. The search incorporated the key words "industrial waste" and "waste management approach" as well as their combination with "manufacturing" and "automotive". The search was focused on papers addressing a situation similar to that in Swedish manufacturing industry and specifically automotive industry; however, papers addressing waste management outside of this scope were also included in the study. The selecting method was based on both keywords a qualitative up-stream and down-stream search for relevant references. The empirical base for the paper relies upon discussions with experts in industrial workshops, in order to verify the results. In addition to the 18 waste management approaches presented in this paper, an additional 19 were identified but omitted. The exclusion was either based on that an approach had a limited link to industrial waste management, or that an approaches was a subsets of another one that is addressed in this paper, e.g. *eco-industrial parks* and *industrial symbiosis* are applications to the concept *industrial ecology*, and *Individual Product Responsibility* and *Extended Product Responsibility* are subsets of the policy/tool *product stewardship*.

3 WASTE MANAGEMENT APPROACHES

3.1 Zero waste

The *Zero waste* focuses on waste prevention, minimisation and reusing by considering waste as valuable resource rather than a problem for companies. It aims to utilise the concept *material efficiently* and uses all material inputs in the final product or changes it into other inputs for another process (Tang, 2008). Matching input and output of different industries is one of the key challenges that need to be solved, possibly by *industrial ecology* through eco-industrial parks, industrial symbiosis, and new technologies (ZeroWIN, 2010, Atlas, 2001). On a smaller scale products also need to be designed to meet the requirements of multiple lifecycles, for example through *eco-design* and design for disassembly and reassembly (Tang, 2008). With the same intention, *Environmentally Conscious Design and Manufacturing (EDCM)* addresses the existing and future relationships between design, manufacturing, and environment. Environmentally conscious technologies and design practices help manufacturers to minimise waste and turn it into a profitable product (Zhang et al., 1997). The *zero waste* vision and *closed-loop* are both directed towards preventing waste rather than managing generated waste, however *zero waste* can be integrated with other approaches including *industrial ecology*, *cleaner production*, pollution prevention, *zero emissions* and natural capitalism. (Curran and Williams, 2012). Furthermore, tools including *Green performance map*, *eco-mapping* and *waste diversion planning system* can be commonly used to pursue *zero waste* vision as all are based on eliminating wasteful usage of energy, material, emissions and resources.

Regulatory factors commonly play a key role to encourage waste minimisation activities; however, geographically limited regulations generally drive costs in the short term. Therefore it is easier to establish and enforce regulations when the economy is good.

3.2 Waste prevention

The *waste prevention* is a vision that focus on both quantitative and qualitative reduction of waste, i.e. lower volumes and lower toxicity before the material or product is converted to waste (Lebersorger,

2008, Lilja, 2009). This definition covers the top three steps of the *waste hierarchy*: prevention, reduction and reusing. However, *waste prevention* neither include recycling, energy recovery, nor product design for recycling and remanufacturing (Lilja, 2009). Discarded material is in this vision considered as waste, even if they are recycled regardless of if money is paid for the material. The *waste prevention* can be strengthened by *product stewardship* via standards, legislations and *cleaner production* through technology optimisation and innovative technologies. Other approaches including *eco-design*, *Environmental Management Systems (EMS)*, *Environmentally Conscious Design and Manufacturing (EDCM)*, *eco-efficiency*, *eco-mapping* and *Green performance map* contribute in obtaining such vision while all of them cover waste prevention step in *waste hierarchy*.

Material efficiency and *waste prevention* both are crucial approaches towards *zero waste* (ZeroWIN, 2010). However, *material efficiency* is a preferred life cycle approach rather than *waste prevention* since the majority of the environmental benefits from waste prevention stem from the decreased requirement to produce materials (Lilja, 2009), as elaborated: "*Waste prevention is the goal ranked highest in the waste hierarchy, but the materialisation of this goal needs actions that are not alternatives for investments in waste recycling, waste recovery or final disposal*".

3.3 Cleaner production

The objectives of the *cleaner production* is to enhance productivity and environmental performance, reduce environmental effects, improve raw material efficiently, reduce water and energy usage, decrease emissions and design for environmental cost-effective products i.e. *Eco-design* (Li and Chai, 2007, EPA, 2003). In comparison with the *eco-efficiency* (Gravitis, 2007), *cleaner production* is based on environmental efficiencies that have internal economic advantages, whereas *eco-efficiency* is based on economic efficiencies that have environmental advantages. Neither of these concepts cover waste utilisation in late life-cycle phases. For instance, unlike end-of-pipe waste management solutions, *cleaner production* focuses on the manufacturing phase of the product life cycle (Gumbo et al., 2003). In addition, this vision cover the least area on *waste hierarchy* among the other visions by just considering reduction stage and it is in line with (Kuehr, 2007) study which put *zero emission* as the next step of *cleaner production* towards sustainability.

Cleaner production and *eco-efficiency* focus on reducing materials inputs and reducing wastes at the level of the firm, whereas *industrial ecology* characterises a development that moves forward from dealing with localised environmental impacts (Gibbs and Deutz, 2005). At the firm level *eco-design*, pollution prevention and green accounting can contribute; LCA tool and process-based strategies e.g. industrial symbiosis are used at the inter-firm level; and material and energy flows are used at the global level (ZeroWIN, 2010). *Cleaner production* pertain also cleaner technology, *Environmental management systems* and *best practice* concepts (Zhang et al., 1997). Cleaner technology associated by using innovative technologies that have economic and environmental benefits for source reduction and eliminating or reducing hazardous waste (Curran and Williams, 2012). Although technological progresses has helped industries to some extend reduce the environmental damages, *best practice* does not solely consist of changes in process but it also include changes from old way of thinking to continuous improvement of all aspects of companies' operations and activities. An example of related tool is *waste diversion planning system* which improve waste recycling performance by track particular material diversion tonnage and total percentage of recycled material regarding weight or volume.

3.4 Zero emission

The *zero emissions* vision is more extensive than *cleaner production* vision or other related concepts such as *product stewardship* (ZeroWIN, 2010). It is closely related to *Eco-design* through LCA and carbon footprint. This vision is in line with pollution prevention and *waste prevention* as all focus on reducing wastes and emissions to zero without decreasing productivity. According to (Kuehr, 2007), *zero emission* is the last step toward sustainability whereby a *closed-loop*, *industrial ecology* (via eco-industrial parks), wastes being used as inputs for other industries. Connection of *zero waste* and *cleaner production* can be found through using of new technologies and analysing material flows (Gravitis, 2007). Various tools are also related to such vision e.g. *GPM* can identify non-productive

outputs of processes in term of rest material, waste and emission to air, water and ground (Kurdve et al., 2012).

4 ANALYSIS

The identified set of waste management approaches have similar approaches and strategies to tackle current environmental issues, which cause confusion for industries who want to minimise generation of waste and emission. The approaches can be classified into visions, concepts, tools, and policies; each of these serve the purpose of reducing waste or the effect of the waste that is generated. Visions are generally unattainable, but serve as ultimate targets to strive for. Concepts represent broad ideas and solutions for how to reach a vision; however, each individual concept is generally not sufficient to reach a vision. Tools generally incorporate a specific process that serves a specific goal, and a set of tools with different application might be commonly utilised to pursue each concept. Policies and environmental regulations are either used to hinder development in an undesirable direction or to steer companies towards a more desirable path. Policies and regulations are imposed by local, national or international authorities; however, depending on the policy itself and the market it targets, the effects may exceed its geographical intent or have a more limited effect.

Figure 1 presents the waste management approaches that were most cited in literature with respect to manufacturing industries. The approaches are mapped according to type (vision, concept, tool, or policy), organisational usage level (management or operation), measurement (quantitative or qualitative), improvement action (technology upgrade, management/decision-making, operational improvement, mind-set changes, or raw material substitution) and number of found citations (based on pair key word search).

		Type	Visions					Concepts					Policies		Tools					
		Waste management approach	1. Zero emission	2. Cleaner production	3. Waste prevention	4. Waste Minimization or Zero Waste	5. Eco-efficiency	6. Eco-design	7. Best practice	8. Environmentally Conscious Design & Manufacturing (ECDM)	9. Closed-loop	10. Industrial ecology	11. Reverse logistics	12. Material efficiency	13. Product stewardship	14. Environmental management system (EMS)	15. Eco-mapping	16. Green performance map (GPM)	17. Waste hierarchy	18. Waste diversion (planning system)
Organisation level	Management	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Operational	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Measurement	Quality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Quantity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Improvement actions	Technological	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Managerial	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Operational	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Raw material substitution	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Mindset	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Citations	"Waste management approach" AND "waste"	40	140	50	434	54	12	70	1	98	76	55	23	12	44	0	0	21	26	

Figure 1: The 18 most cited tools, concepts, visions and policies categorised

According to figure 1, most of the approaches are applicable for management, but only one of the visions and two of the concepts are applicable for the operational level. This illustrates a gap where the practical operational processes do not have sufficient background or purpose. The lack of vision and purpose may lead to that hands-on environmental efforts, tools, and policies introduced at the shop-floor are met with distrust and seen as unnecessary work. This inevitably leads to inefficient waste management and non-sustainable production. In order to improve waste management at the operational level, the vision and concept associated with each tool needs to be made clear for the users.

Only half of approaches focus on both a quantitative reduction of waste and a qualitative reduction i.e. reduced toxicity. Treatment of hazardous waste and toxicity disposal is therefore the next major concern in waste management activities. Around 77% of all approaches note that better management and decision making lead to environmental improvement, while 88% of them

recommend operational improvement of the actual waste generating processes as well. Technology upgrade, raw material exchange and mind-set change have been addressed by approximately 30%. This indicates that operational improvement and managerial decisions play an important role in environmental improvement.

In figure 2 all chosen waste management approaches are mapped according to product life cycle phase and waste hierarchy steps. The mapping is based on the literature review; however, the specific approaches are not necessarily static and rarely directly linked to life-cycle phases or waste hierarchy. Consequently, the table should be used indicatively for the whole set of approaches, not for drawing conclusions for single approaches.

Product Life Cycle	End of Life	1	1 10	8, 9, 1 10, 11 13	8, 9, 10, 11 12, 13	5, 6, 1 9, 10 12	1 5, 8
	Consumption	1	1 8, 9, 11	1, 4 8, 9, 11	4 8, 9, 11 12	1, 4 5, 8, 9 12	1, 4 5, 8
	Manufacturing	1 16	1 10 16	8, 9, 1, 4 10, 11 16, 18	8, 9, 2, 4 10, 11 18 12	1, 2, 3, 5, 7, 8, 4 9, 10 16 12, 14	1, 2, 4 5, 7, 8 16
	Raw material Processing	1 16	1 10 16	8, 9, 1, 4 10, 11 16	8, 9, 2, 4 10, 11 12	1, 2, 3, 5, 7, 8, 4 9, 10 16 12, 14	1, 2, 4 5, 7, 8 16
	Design	1	1	1, 4 6, 8	4 6, 8 12	1, 4 5, 6, 8 12	1, 4 5, 6, 8
		Landfill	Energy Recovery	Recycling	Reusing	Reduction	Prevention

17 - Waste Hierarchy

Figure 2: Integrated table of waste hierarchy and product life cycle, with numbers from Figure 1

The waste management approaches that cover the most areas in the matrix above are *zero waste*, *eco-design*, *industrial ecology*, *waste prevention*, and *cleaner production*. These are either visions or concepts, which is logical since both tools and policies need to be more detailed and therefore have a more limited scope. The majority of waste management approaches refer to *reduction*, followed by reuse, *recycling*, and *waste prevention*. The dominance of *reduction* approaches is natural since waste reduction has a direct effect on manufacturing activities at the factory, reducing volume, cost and complexity resulting from waste. Therefore, non-environmental benefits might be an incentive for manufacturing companies to more focus on reduction. The limited number of approaches linked to *landfill* and *energy recovery* is a direct result from this study's focus on manufacturing; however, it also shows that these end-of-pipe solutions have a weak connection to a product's life phases and waste management activities in manufacturing. In addition, both *landfill* and *energy recovery* pose primarily technical difficulties, which is not shown in this study.

Approximately 70% of the waste management approaches have impact on the manufacturing phase of the product. 77% of approaches influence raw material processing phase while half of them affect the end of life phase. Moreover, design and consumption phase can be influenced by 44% of the approaches. As the matrix shows, the manufacturing phase and raw material processing phase of product life cycle are often the primary targets of the approaches; however, the evidences of actual use of them among manufacturing companies is not so common.

5 CONCLUSION AND FUTURE RESEARCH

The most frequent barriers toward waste management and sustainable production is according to this study: technical limitation, cultural shifts, lack of EU-level goals on waste prevention and material efficiency, hindrance for waste prevention due to low waste disposal costs and absence of standards for reusable products. Achieving sustainable production therefore, requires a structured approach with best use of existing tools and concepts integrating with environmental policies, and/or developing new ones in order to prevent waste in the first place. Corporate environmental managers should realise that enhancement of waste minimisation is more probable by hands-on approaches at the facility level and consequently integrated methods should be used at shop-floor to motivate companies to formalise and follow their waste minimisation actions. Most of these actions are not technology driven. They constitute material substitution, waste separation, recycling, process improvement, preventing leak and spills, inventory control and better management procedure. Hence, future waste minimisation might not take place on technological changes but on mind-set changes, operational improvement and

management techniques in order to reduce the quantity of waste while enhance the quality of waste and residual material. Re-examination of production processes and operations, and redesigning material flow and production system is necessary to identify waste minimisation opportunities and enable remanufacturing, recycling, reusing, refining and recondition of the material. Moreover, taking advantage of other facilities experiences in waste minimisation actions and communicating these among stakeholders, staffs, customers and supplier will facilitate such paths.

The study is an introduction to the research on different approaches regarding waste management, but more data will be needed to describe their specification and interaction in detail. Examples on future research are to study each approach or subset in respect to a more detailed organisation level, improvement processes and direct and indirect effect on product life cycle phases. Moreover, the application of each approach in different manufacturing companies would be essential to see how these concepts are implemented in practice.

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SUSTAINABLE MACHINING - CORRELATION OF THE OPTIMIZATION BY MINIMUM ENERGY, MINIMUM MANUFACTURING TIME AND COST OF PRODUCTION

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ABSTRACT

The machining process leads the indices of productivity and employability in a world level and has an enormous influence at social and economics standards, however it requires machinery that consume high levels of energy, chemical fluids and has great emissions of greenhouse gases. In our days as governments and clients increase their demands for the degradation of ecosystems, also increase the need for companies to implement sustainable policies and improve their environmental performances. The reduction of energy consumption and consequently the reduction of fossil supplies are a major source of concern at this level. This article establish a bridge between the classical approaches of optimization models of machining processes (Maximizing Production Rate and Minimizing Production Cost), and reduction of electricity. For a single pass turning it was used a mathematical model to analyse the data taken as a reference, optimizing the critical parameters of consumption of time, money and energy.

Keywords: Machining, Sustainability, Optimization

1 INTRODUCTION

In the last years arises a word that had become acquainted to the all citizens - Sustainability - and the questions related with environment became to take lead in the world leaders agenda. The common meaning for sustainability is how the systems remain diverse and available all over the time, the idea is to produce today without compromising tomorrow (United Nations, 1987). At this juncture has been growing the sustainability paradigm in machining, which involves economy, environment and society, the three axes of all organizations. However they not always follow the same direction, the various sciences that have been studying the subject, need to create horizontal objectives in all areas of activity (Herrmann *et al.*, 2008; Gutowski, 2011).

The focus of the rationalization includes the energy production, and even being an issue that have much of the concerns of nations and organizations worldwide, because it is crucial for maintaining production standards and high standards of living, it has been overlooked in the corporate management. Without energy there is no economy, without economy living conditions will necessarily be more precarious, but without environment, resources become scarce and living increasingly unfeasible.

Machining is one of the process that more damage the environment, because to produce, it requires polluting products. Studies have confirmed that production consumes large amounts of energy, and outputs to the environment large amounts of CO₂, since these two aspects are correlated (Gutowski *et al.*, 2004; Gutowski *et al.*, 2005; Kopac *et al.*, 2009a, McLean *et al.*, 2008). The search for better products has taken into consideration the factors of time and cost, to become viable, but for what was described, seems to matter to add a new factor, create more sustainable products. Like this emerges the issue in which this study focuses on, the optimization of a machining process, with emphasis on energy consumed.

This study creates a bridge between the classical and actual methods of analysis, in search of the possible existence of an optimum point of production, which avoids wasting energy, making it

cheaper and more efficient, always keeping high standards of productivity. The balance between these parameters is crucial for the acceptance of a new way of machining by the leaders, because no matter how size, all enterprises have the potential for cost saving, improving their environmental performance (Gutowski *et al.*, 2011).

2 STATE OF THE ART

Significant research has been undertaken in order to identify indicators of sustainable machining analysis and methodologies of improvement of such parameters (Kara *et al.*, 2009a; Lu *et al.*, 2010).

Kopac J. *et al.* (2010a) focused their studies on sustainability in machining studying alternative forms of machining, less polluting, such as cryogenic machining, which uses cryogenic fluids rather than oil-based lubricants, and machining of high pressure jet concluding with their experiences, that both technologies are cleaner than the common methods of machining, less assaulting for the environment and economically viable, despite the initial costs are substantially higher (Kopac, 2009b; Kopac *et al.*, 2010b). The authors report that there is still the way to go and the advantages of the three pillars of sustainability that comes from sustainable practices (Devoldere *et al.*, 2007).

When it comes to optimization, multiple objective functions are presented, with different purposes, the most common is the authors study the minimization of production cost, or maximize the productivity rate basing their analyzes on cutting parameters (Lee *et al.*, 2000; Gutowski *et al.*, 2006a; Joshi, 2006) but new currents have been presented, covering energy issues. Studies analyze the impact of selection of design parameters on energy consumption, concluding that high cutting speeds translate into energy earnings per unit produced. (Diaz *et al.*, 2009; Kopac *et al.*, 2010c; Mativenga *et al.*, 2011; Dietmair *et al.*, 2009). Product quality and energy consumption are the keys to this process. Kara *et al.* (2009) developed a mathematical model of economic optimization of machining, taking into account the energy used directly and indirectly as well as the costs associated with the pollutants emissions into the atmosphere. The results of this analysis leads to the conclusion that the inclusion of external energy costs does not, by itself, a more effective machining, since its contribution is not high.

3 MATHEMATICAL MODELS

This section presents the equations for the three models in analysis, where the purpose is to obtain an optimal result, function of the cutting speed and feed rate.

3.1. Minimum Production Time Model

To determine the minimum production time, the classics approaches sub divided the Total Production Time in three parts: Brewing Time (t_1 , min), which includes the machine set-up time, checking time and the total idle time, Cutting Time (t_2 , min), related to the material removal time, and the Tool Exchange Time (t_3 , min), function of Tool Life Time (T , min) and Cutting Time, since it is the total time connected with the changing tool accordingly with its life time, number of cutting edges and time of usage. So the final mathematical expression which measure the entire time required to produce a metal part in a turning single pass is:

$$Tt = t_1 + t_2 + t_3 \quad (1)$$

$$T = \frac{C}{V^x \times f^y \times a_p^z} \quad (2)$$

To evaluate the tool life time the authors chose the Extended Taylor's Tool Life equation (2) once it is related with the straight relation between cutting speed and feed rate with the Cutting Time, which are the constrains to optimize. This connection is valid for all machining operations and is the basis for more complex models.

$$T_t = t_1 + \frac{l \times \pi \times D}{f \times V} + \frac{\frac{l \times \pi \times D}{f \times V}}{\frac{C}{V^x \times f^y \times a_p^z}} t_f \quad (3)$$

Gathering the two equations shown above, results in the final equation where is possible to determine the Total Production Time (T_l in min), where l is the part length (pol.), D is the diameter (pol.), f is the feed (pol.), V is the cutting speed (fet/min), a_p the depth of cut (pol.), t_f the tool changing time (min), and C, x, y, z the Extended Taylor's tool life equation constants.

3.2. Minimum Production Time Model

For long time now, has been accepted that the Total Production Cost (C_u) is one of the major management indicators and should be optimized, in parallel has also been acknowledge that the conditions during cutting are the better way to get it.

The classical approach is to calculate the Total Production time by adding the Preparation Cost ($C_1, £$), the Machine Cost ($C_2, £$), the Worker Cost ($C_3, £$) and Tool Cost ($C_4, £$)

$$C_u = C_1 + C_2 + C_3 + C_4 \quad (4)$$

In the equation 5 the times (t_1, t_2, t_f and T) keep the meaning described in the section above, and φ is the Machine Cost Rate (£/min), β is the Labour Cost Rate (£/min) and γ is the Tool Cost per cutting edge (£). Therefore the decision makers can optimize the cutting parameters in order to minimize the Total Production Cost ($C_u, £$).

$$C_u = C_1 + \varphi(t_1 + t_2 + t_f \frac{t_2}{T}) + \beta(t_1 + t_2 + t_f \frac{t_2}{T}) + \gamma(\frac{t_2}{T}) \quad (5)$$

3.3. Minimum Energy Model

The environmental issue play a key role in our society, and one of the most important agents in the action against environmental aggression is the reduction of consumption of Electrical Energy, hence the measure of the energy consumption during machining operations should be adopt for all enterprises, and more important, decrease this consumption.

The formulation to this account is expressed on equation (7) where the inputs are the machining parameters with the exception of the machine Standby Power Consumption (P_0 , ft.lbf/min) and the specific energy (ψ , ft.lbf/min.pol³/min). The energy require for the turning operations was evaluated into: Unproductive Energy (E_1 , ft.lbf) that is the necessary energy to remove the material, Cutting Energy (E_2 , ft.lbf), which is the energy that the machine consumes during the set-up time, idle time, Tool Changing Energy (E_3 , ft.lbf) required during the time to exchange the tool and the Tool Edge Energy (E_4 , ft.lbf) means the energy necessary to produce the tool, by number of cutting edges, where $\square$ is the Energy Consumption per cutting edge of the tool (ft.lbf).

The energy evaluation (Total Energy Consumption) was based in the equation (6) proposed by Gutowsky *et al.* (2006b), which has been referenced in several articles since then (Reis *et al.*, 2011; Rajemi *et al.*, 2010) and relates the energy required to start-up the machine (P_0) and energy required to the operation, proportional to the material removal rate ($\dot{v}$, pol³/min).

$$E = (P_0 + \psi \times \dot{v})t \quad (6)$$

$$EE = E_1 + E_2 + E_3 + E_4 \quad (7)$$

Joining both equations it is now possible to evaluate the Total Energy Consumption in a one pass turning operation (EE , ft.lbf):

$$EE = P_0 t_1 + (P_0 + \psi \times \dot{v}) t_2 + P_0 t_3 + \phi \frac{t_2}{T} \quad (8)$$

3.4. Minimum Modified Cost Model

With the deduction of the last two algorithms (Total Production Cost and Total Energy Consumed), the authors also optimized the Total Cost of Production taking into account the Cost of Energy Consumed, represented in the equation (9). The meaning of the constant μ is the Cost of the Energy (£/ft.lbf).

$$CC = C_1 + \phi(t_1 + t_2 + t_f \frac{t_2}{T}) + \beta(t_1 + t_2 + t_f \frac{t_2}{T}) + \gamma(\frac{t_2}{T}) + \mu(P_0 t_1 + (P_0 + \psi \times \dot{v})t_2 + P_0 t_3 + \phi \frac{t_2}{T}) \quad (9)$$

4 OPTIMIZATION METHOD

The computer modelling to obtain an optimum turning point, having the cutting speed as a constrain, was based on Newton's method. This method solves the problem by approximating the function iterations under study by a quadratic function. In one neighborhood, the function can be approximated by a Taylor series extension to 2nd order. It is a good methodology for non-linear problems.

1. Formulation : $g(x) \leq 0$ $MinF(x)$	2. Newton's Method: $\nabla f \times dx = -f$ $L(x, \lambda) = F(x) + \lambda \times x \wedge$ $\lambda \geq 0 \wedge \lambda \times g(x) = 0$
3. Algorithm: $\begin{cases} \frac{\partial L}{\partial x} = 0 \\ \lambda \times g(x) = 0 \\ \begin{cases} \lambda \geq 0 \\ g(x) \leq 0 \end{cases} \end{cases}$	4. Check if: $f = \begin{bmatrix} \frac{\partial L}{\partial x} = 0 \\ \lambda \times g(x) = 0 \end{bmatrix}$ $dX = \begin{bmatrix} dx \\ d\lambda \end{bmatrix}$
a) Function: $F = f(x)$	b) Beginning $x_0 = \bar{x}$ $\lambda = -\frac{1}{g(x)}$
c) Step: $dx = -\frac{f}{\nabla f} \Leftrightarrow dx = -f \times (\nabla f)^{-1}$	d) Update : $x^{i+1} = x^i + dx$
e) Check the constrains while: $g(x) > 0$ $S = S \times S_0$ $x^{i+1} = x^i + S \times dx$	f) Check the reduction of Objective function while: $F^i < F^{i+1}$ $S = S \times S_0$ $x^{i+1} = x^i + S \times dx$
g) Update λ 's while: $\lambda^{i+1} < 0$ $S = S \times S_0$ $\lambda^{i+1} = \lambda^i + S \times dx$	5. Check convergence: $\ L\ _{\infty} \leq erro1$ $\ \lambda \times g(x)\ _{\infty} \leq erro2$

In this model x is a vector with n parameters, in the cases simulated, x is composed of two components - Cutting Speed and Feed rate. The Software used in the simulations was MatLab.

5 COMPUTATION

The long term goal is to turn the metal cutting process into a sustainable procedure. For the purpose in this study, the potential parameter to environmental improvement is the Electric Consumption.

The authors present numerical examples to illustrate the proposed approach and solutions, to prove the possibility to solve the real problems. The first concern is to choose the constrains, because they must ensure that the simulation will be a reliable copy of the real problem. In machining process is recognized that the cutting velocity and feed rate are the obvious choices, to optimize the process in relation of cutting parameters. The window optimization, and the values of parameters and constrains,

was done accordingly with literature review (Akturk *et al.*, 1996; Gutowsky *et al.*, 2004; Mativenga *et al.* 2011a, Mativenga *et al.* 2011b) and taking into account a feasible combination of cutting velocity and feed rate, for the part to be turned. The values used in the simulations are summarized in table (2) and results obtained are presented in the table(3) and discussed below.

Table 2: Values from the optimization constants

Constant	Value	Constant	Value
l	5,000	C ₁	3,500
D	2,000	φ	9,000
C	40960000,000	β	12,000
x	4,000	γ	1,500
y	1,400	P ₀	7346118,727.10 ⁻⁶
z	1,160	ψ	4916,119.10 ⁻⁶
t _f	2,000	φ	1106343,181.10 ⁻⁶
t _l	7,000	μ	0,2
a _p	0,040	V _{max}	700,000
V _{min}	300,000	f _{max}	0,020
f _{min}	0,005		

Table 3: Results from the optimization models

Model	Time (min)	Cost (£)	Energy (ft.lbf)	Cost Modified (£)
Optimum value	7,3414	164,2329	53,9767.10 ⁶	168.5283
Velocity (ft/min)	511,2040	506,7389	502,0093	506,4228
Feed (pol)	0,02	0,02	0,02	0,02

6 CONCLUSIONS

With the analisis of the numeral example is possible to conclude that this optimizing method is realistic and practical to obtain reliable results for optimization of machining operations and useful when models are complex. Like this the managers can rethink their environmental policies and invest more in a sustainable production.

The optimum condition for cutting, based on the speed of material removal, with the aim of obtaining the minimum energy consumed during the turning process, meets the criteria for minimum operating cost. Is it feasible for companies to choose a less aggressive machining with the environment and population and remain competitive in the market.

This work aims to show that there are simple mechanisms and extreme accuracy that can serve as a decision support of business leaders.

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A REVIEW OF LIFE CYCLE ASSESSMENTS OF RENEWABLE ENERGY SYSTEMS

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ABSTRACT

A review of life cycle assessments (LCAs) of wind energy published in the past few years are presented in this paper. The aim is to identify the differences of the developed methodologies, in particular, the factors such as methods used, energy performance and influence of uncertainty. Each of the factors is addressed to highlight the shortcomings and strengths of various approaches. Potential issues were identified regarding the way LCA is used for assessing environmental impact and energy performance of wind energy. It is found that the potential of incorporating the quantification of uncertainty in the manufacturing phase has not been studied elaborately. A framework methodology has been proposed in this paper to address this issue.

Keywords: Uncertainty, LCA, Manufacturing processes.

1 INTRODUCTION

Prompted by current problems of energy supply and the implementation of commitments in climate change awareness, the world is searching for renewable energy sources (Ometto et al., 2009). At the end of 2009, 1.8% of global electricity demand was met by wind energy with almost 160 GW of installed capacity (Davidsson et al., 2012). This makes wind energy an important future energy option. Wind and other renewable energy systems are often assumed to be environmentally friendly and sustainable energy sources in much of main stream debate. All energy systems however have various environmental impacts and a consistent method of evaluation for analysing all aspects of a given source of energy is required as without such a method, it will be difficult to compare them and make the right decisions when planning and investing in future energy systems (Davidsson et al., 2012). Life Cycle Assessment (LCA) is a popular way of measuring the energy performance and environmental impacts of wind energy. Many researchers have attempted to resolve these issues associated with wind energy using various approaches. This paper will focus on how uncertainty can be incorporated into LCA for the manufacturing phase of wind energy systems. This will be followed by a proposed methodology incorporating uncertainty with LCA in developing renewable energy systems.

2 LITERATURE REVIEW

Padey et al. (2012) presents a methodology that offers an alternative to detailed LCA of wind electricity. A detailed analysis of the origin of wind turbine impacts provided through the assessment of one wind turbine inventory from the Ecoinvent database and survey of literature highlighted the importance of three types of parameters namely: a geographical dimension, directly related to wind conditions through the load factor (L); a technological dimension, with parameters related to the type of technology and materials used for the wind turbine; and a methodological dimension with the lifetime parameter. Sensitivity studies were then performed for the greenhouse gas (GHG) impacts, then for GHG performance, varying these three parameters to identify which is most influential. The findings from the sensitivity analysis lead to the definition of a regression from the sample relating the wind electricity GHG performance to a single parameter: wind speed. Davidsson et al. (2012) has identified an example of dependence on methodology implemented by Martinez et al., (2009 a and b). The same authors perform an LCA on the same model of wind turbine, at the same wind farm with the same assumed production, but using different impact assessment methodologies giving significantly different results. Martinez et al. (2009 a) uses Eco-Indicator 99 method using 11 different impact factors while Martinez et al. (2009 b) uses CML (Centre of Environmental Science of Leiden University) methodology presenting environmental impacts in 10 different impact categories presented as equivalents of different emissions as well as cumulative energy demand. It is noted that for the resulting energy performances, Martinez et al. (2009 a) presented an energy payback time of 0.4 years while Martinez et al. (2009 b) presented an energy payback time of 0.58 years. Therefore, the levels of uncertainty in the different impact assessment methodologies affect the energy performances hence the need to quantify this uncertainty.

Fleck and Huot (2009) employs LCA to compare the environmental impacts, net energy inputs and life cycle cost of two systems: (1) a stand-alone small wind turbine system and (2) a single home diesel generator system. Life cycle cost methodology was used to account for the time value of money on an investment. The net energy input of a unit process was calculated based on the energy inputs and outputs of a process. Results showed considerable environmental and net energy input benefit for wind power while in terms of cost, the results were comparable. Uncertainty was calculated for the key environmental impacts using a Monte Carlo simulation in order to determine their expected range. Pehnt (2006) investigated a dynamic LCA approach for renewable energy technologies with respect to change of technology, processes, electricity mix etc. extrapolating these context dependent parameters into the future. With this approach, environmental problem areas, which are inevitably connected with renewable energies, are analytically distinguished from those imported into the system by the background system, i.e. supply of energy and materials. In a sense, this could be referred to as a sensitivity analysis with respect to technological change, processes or transportation. Merugula et al. (2012) evaluated the effect on life cycle energy return-on-investment (EROI) and emissions of incorporating carbon nanofibre in wind turbine blades. The benchmark life cycle inventory from Ecoinvent and its modifications to include upstream carbon nanofibre production were evaluated for energy intensity and midpoint impacts. This highlighted the design of the analysis showing the variations imposed against the established LCA which could be referred to as a sensitivity analysis with respect to materials used for production. A step change in comprehensiveness is employed by Garret and Ronde (2012) by conducting LCAs whereby the wind turbine's entire bill of materials is assessed, accounting individually for around 25,000 parts that make up the wind turbine and, in total, around 99.95% of the total mass of the entire power plant. The LCAs assess all stages in the life cycle from cradle to grave. Also, in the manufacturing stage, the LCA considers information from all Vestas' global sites, and the use phase relies on Vestas' real-time performance data of over 20,000 monitored wind turbines around the world, covering around 20% of the current worldwide installed wind capacity (Garret and Ronde, 2012). This level of detail and reliability in data represents a state-of-the-art approach to LCA modelling of wind power reducing the levels of uncertainty that could affect results.

Environmental impacts of wind energy are still a matter of controversy as Tremeac and Meunier (2009) points out. For several reasons, some of which are addressed in this paper, the results vary widely for different wind power assessments and even the type of results that are presented. It could be added that LCA methodology during the course of these studies has been and is still

evolving. The critique expressed here is not directed towards the specific assessments but rather, attempts to address the need for discussion on how the manufacturing processes should be quantified and assessed. The manufacturing phase usually has the highest impact on the environment. This raises the following research questions to be addressed in this research, for example, “how can the manufacturing processes for energy producing facilities like wind turbines be optimized?” and “what are the best methods to achieve this?” For future long term planning, this will assist in optimizing the impact of design variations of renewable systems. A summary of the above reviews is highlighted in Table 1.

Table 1: Summary of reviews

Paper	Authors	Aim	Method	Gaps	Geographical location	Product type
Life cycle assessment of wind power: comprehensive results from a state-of-the-art approach	Garret and Ronde (2012)	Paper aims to present a transparent and robust approach to LCA modelling of wind power systems	GaBi DfX software, Vestas internal master-data systems, CML impact assessment method	Recommendation that wind turbines are compared within equal wind classes and appropriate sensitivity analysis included to assess primary assumptions and uncertainties	Worldwide	2MW Grid streamer turbine
A simplified life cycle approach for assessing greenhouse gas emissions of wind electricity	Padey et al. (2012)	Study aims to develop a methodology towards a simplified approach as an alternative to performing a full LCA	Ecoinvent database, regression, Sensitivity analysis	Quantifying the influence of technological parameters on GHG performance for low wind speeds	USA	Various wind turbines systems
Comparative life cycle assessment of a small wind turbine for residential off-grid use	Fleck and Huot (2009)	Direct comparison of the environmental impacts, net-energy inputs and life-cycle cost of a stand-alone small wind turbine and a single home diesel generator	Monte Carlo simulation, Life cycle costing	Comparison of grid-tied small wind turbines to grid provided electricity on both a GHG and economic level	Canada	Stand-alone small wind turbine
Dynamic life cycle assessment (LCA) of renewable energy technologies	Pehnt (2006)	An investigation of the environmental performance of renewable energy systems in view of future	Umberto software/database, parameters extrapolated into the future (2030)	Extrapolating the various manufacturing processes into the future taking into account uncertainties in various manufacturing processes	Germany	Renewable energy technologies

		developments				
Reinforced wind turbine blades – An environmental life cycle evaluation	Merugula et al. (2012)	Paper aims to assess the incorporation of carbon nanofibre in wind turbine blades	Ecoinvent database, energy return on investment	Continued investigation if the results will lead to more efficient operation and higher deployment rates	USA	Reinforced wind turbine blade

3 METHODOLOGY

According to Malca and Freire (2011), uncertainty analysis is a systematic procedure to determine how uncertainties in data are propagated throughout the life cycle of a model and how they affect the reliability of the life cycle's outcomes. Malca and Freire (2011) identified the following sources of uncertainty in LCA; parameter uncertainty which arises from lack of data, empirical inaccuracy (e.g. imprecise measurements), and unrepresentativeness of data that are incomplete or outdated; scenario uncertainty, which reflects the inherent dependence of the outcomes on normative choices in the modelling procedure for example, choice of functional unit, definition of system boundaries, or selection of allocation methods; model uncertainty, which is due to the use of mathematical relationships between model inputs and outputs that simplify real-world systems. In this paper, a robust approach is proposed to address and incorporate uncertainty in the manufacturing phase of wind turbine systems. The main steps of this approach are summarized as follows:

- A sensitivity analysis will be conducted in which the variation in a single parameter (e.g. manufacturing process) is tested to see how the results are affected. This aims to identify parameters with the highest impact on the output of the model;
- A more complete approach for compiling life cycle inventory (LCI) data for the manufacturing phase. For example, (1) recording enough observations for each process to characterize probability distributions, (2) the use of formal expert elicitation to develop distributions based on expert's estimates of possible and probable values and (3) a literature review to identify variation ranges and assign appropriate probability distributions for the most influential parameters;
- Monte Carlo simulation will be used for calculating probability distributions of the output variables based on the uncertainty within selected input parameters to determine confidence intervals and other indicators of robustness;
- An uncertainty importance analysis will be conducted in order to identify parameters that contribute most to the overall output variance and hence, guiding further research to reduce their uncertainty.

Plevin (2010) opines that single sensitivity analysis generally underestimates the uncertainty in a model. The proposed methodology requires that sensitivity is assessed with parameters varying simultaneously i.e., using Monte Carlo simulation. Figure 1 below provides an overview of this research.

4 DISCUSSION

The goal of modelling uncertainty in the input variables of LCI and LCA models is to better understand a range of results to associate with environmental impacts. To reduce uncertainty in the definition of probability distributions, best practice should be developed as regards to the definition of appropriate probability distribution types as well as uncertainty ranges. It is infeasible to comprehensively model all sources of uncertainty in complex systems by LCA. Due to the complexity of wind turbine LCA models, including all types of uncertainty will be difficult if not impossible. In the current research, these appear to be the different sources of parameter uncertainty shown in various studies, as well as specific sources of model or scenario uncertainty that are exceptionally relevant to the study (Lloyd and Ries, 2007). It may however be sufficient to consider only the most important sources of uncertainty. The type of uncertainty that will be included in the proposed methodology should be explicitly defined, and the potential implications and reasons for omitting

other types should be discussed. Strategies for identifying the types of uncertainty that are considered as important contributors to the overall uncertainty need to be researched further. Although LCA databases such as Ecoinvent contain a significant amount of data and provide information on uncertainty, the lack of widely available LCI data beyond the European and American context will impede quantitative uncertainty analysis. International agreement on the best life cycle impact assessment (LCIA) methods to be used can assist in clarifying which uncertainty should be considered depending on the goals of specific case studies.

For routine LCA applications, models and choices should reflect preferences of decision makers. The significance of the results depends on the choice of methods, which in itself depends on goal and scope definition. For assessments that might prompt high financial investments, a confidence interval of 95% is appropriate. In cases where alternatives that have been investigated perform relatively equally with respect to other criteria, lower confidence levels may be sufficient. Failing to analyse the variation in the different manufacturing processes could lead to misleading or biased estimates that would impose unnecessary costs without accruing the benefits that motivate the current debate about renewable energy technologies.

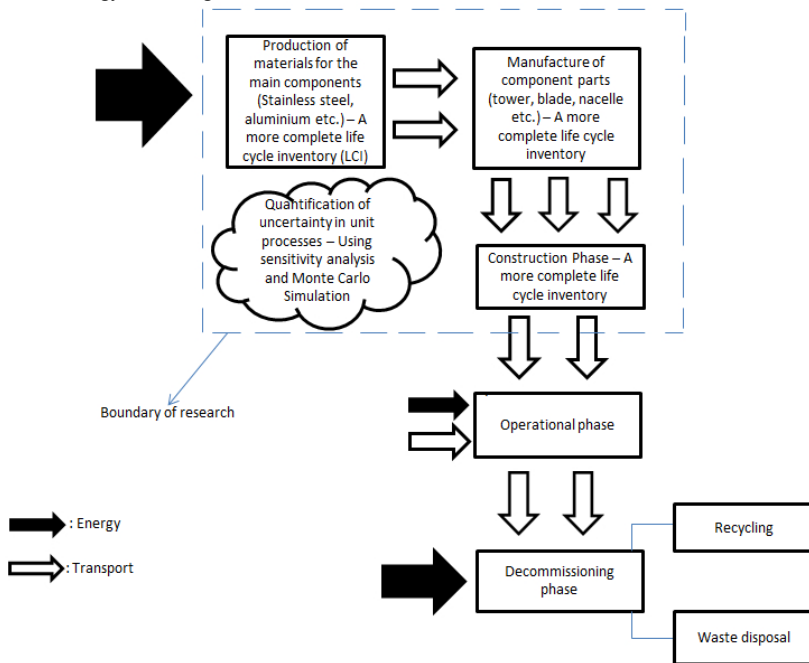


Figure 1: Diagram giving an illustration of the overview of this research.

5 CONCLUSION AND FUTURE WORK

Understanding uncertainty in the manufacturing phase is a critical requirement for the sound investment, policy and environmental decisions about renewable energy. In this paper, uncertainties encountered during modelling the life cycle in the manufacturing phase are outlined and a guide to model these uncertainties is presented. The technique described in the paper can be used to improve the understanding and representation of uncertainties associated with manufacturing processes, thus enabling to improve decision making with respect to the use of LCA at the early design stage of renewable energy system. To aid in enabling reliable quantitative uncertainty analysis, the LCA community should develop a better understanding of the importance of different types of uncertainty and develop protocols for reliably characterizing and analysing uncertainty in LCA.

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TIDAL AND MARINE ENERGY IN THE UK– IDENTIFYING THE FUTURE CHALLENGES FOR SUPPLY CHAIN DEVELOPMENT

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ABSTRACT

The purpose of this paper is to investigate the current technical and operational supply chain issues surrounding the development of tidal and marine energy production in the UK. The paper outlines the market and growth potential of tidal energy production in the UK before identifying the key supply chain themes surrounding tidal energy production including an analysis of the portability and transferability of current supply chain thinking and development from other renewable energy systems such as wind turbine technology towards the development of tidal energy supply chain systems. The paper closes by identifying the major challenges that the UK supply chain must overcome in order to develop a comprehensive and robust supply chain system.

Keywords: Supply Chain, Renewable Energy, Tidal Energy.

1 INTRODUCTION

Successive UK governments have focussed on renewable energy technologies and systems in an attempt to resolve our impending energy production crisis as well as meeting various environmental carbon reduction targets. It can be argued that wind turbine technologies are well established with its associated UK supply chain now beginning to develop and grow for both the offshore and domestic power generation markets (<http://wind-energy-the-facts.org>). The next developmental stage is now focussing upon wave energy systems in the form of tidal and other marine energy systems. Court (2008) goes on to state that the estimate for the world production of wave energy varies significantly, from between 8,000 to 80,000 TWh/y, although that which is convertible to electricity has been estimated to be considerably less and quoted to be around 2,000 to 4,000 TWh/year. For the UK, Court's report states that a practical generating capacity of 700TWh/y is likely which is almost double today's electricity consumption.

However, some of the energy produced will prove to be impractical to harness and estimates of economical recovery of wave energy suggest that wave energy devices could contribute to around 50TWh/y of the UK's total energy demand. The issue of using wave power over wind power systems is that wave power is much more predictable than wind power and increases during the winter, when the electricity demand is at its highest. In 2009, the Parliamentary Office for Science and technology stated that the UK has approximately 35% of Europe's total wave resource, the waves with the greatest energy are situated off the northwest coast of Scotland, where the power (measured in energy

per second) averages almost 50kW per metre and can reach 90kW per metre thus providing huge potential for serious energy production capability and capacity. Also, the seas off the southwest coast of England and Wales are also high in potential and so it is possible from a supply chain perspective to start to identify the key location points from which a local supply chain system will need to develop and emerge.

To further complicate the supply chain logistics issue, wave energy is highest in open seas, and this energy is reduced as the waves move closer to shore, such that by the time the wave hits the shore, it is estimated that it has lost 90% of its original energy. Therefore, to maximize recovery of wave power, wave power devices should ideally be located offshore, before the waves lose energy in shallower waters. This can therefore complicate significantly the supply chain and logistics issues surrounding the; locating, building, supply and maintaining the energy generating system when they are located a number of miles off shore.

2 CURRENT RENEWABLE ENERGY SYSTEMS – SUPPLY CHAIN ISSUES

The Carbon Trust's Marine Energy Challenge (MEC, 2011) estimated that 3 GW of wave and tidal stream capacity could be installed by 2020, generating approximately 8 TWh/y of electricity, which represents 2.1% of electricity supply in 2020. Estimates are that 7.8 TWh/y of this 8 TWh/y resource is near-shore and 0.2 TWh/y is shoreline wave energy. The MEC suggests that this capacity would constitute a substantial proportion of between 1.0 GW and 2.5 GW each of wave and tidal energy expected to be installed across Europe.

As is the case for wave power, tidal and current stream energies are both predictable and consistent. The MEC predicts more favourably that the UK possesses approximately 50% of Europe's tidal resource (compared to 35% stated by a government parliamentary report). The UK total resource has been estimated at approximately 110 TWh/y, with approximately 22 TWh/y, being technically recoverable, thus representing approximately 6% of the UK's electricity demand (Tidal Stream – Phase II, Marine Energy Challenge, 2005). In the short-term, the market opportunities for tidal turbine power have been forecast at a total capacity of 20.9 MW over the period 2004-2008, made up of 15.4 MW from tidal current turbines and 5.5 MW from tidal stream generators. In addition, the forecast for the UK was 17.4 MW out of the 20.9 MW total, or 84% of the total.

In order to realise the potential of wave power, it is critical that the UK energy sector ramps up the development and production of wave energy technologies. Court, 2008 states that it is likely that during the introduction of these sustainable energy technologies, some difficulties will be experienced in obtaining materials from domestic suppliers. In most instances, the market for renewable energy technologies is not yet mature enough to support established supply chains of any size. This may be related to uncertainties regarding the specifics of which materials are required, as much of the technology itself is developmental. Alternatively, the supply chains may be largely non-UK based, as is currently the case for wind turbine generators, for example.

In wind power, although the UK has world-class developers and consultants, there is currently very little manufacturing capacity in the UK and much of the value of wind-power projects goes abroad. There are no established turbine manufacturers and very few UK companies export components. However, the UK is home to both wind turbine rotor blade and tower manufacturing facilities of the world's largest wind turbine manufacturer. In addition, there are indications that with the increased commitment to wind power and with the large number of consented wind power developments, that UK based companies are positioning themselves to supply into this market, and there are certainly a considerable number of companies with the capability to do so.

For example, a UK based company is developing world-leading, direct drive turbine generator technology, and a UK based Research and Technology Organisation (RTO), with industrial partners, has developed radar absorbing materials which should see considerable global exploitation in wind turbine applications. The UK has established itself as an early market leader in marine (tidal stream and wave) power generation with approximately half of the world's current technology developers (approximately 30) headquartered in the UK. In addition, the UK has pioneered the establishment of shared facilities for the testing of wave and tidal devices.

In comparison, currently, there are few marine energy devices / technologies which have reached full-scale testing and, of these, the front-runners currently have, and foresee, no immediate materials

supply (chain) issues, as construction is largely utilising the UK's existing offshore technologies and know-how. The UK is very active in R&D for sustainable energy, through such initiatives as SUPERGEN, the Sustainable Power Generation and Supply Programme <http://www.supergen-marine.org.uk/drupal/>).

3 WAVE & TIDAL ENERGY SUPPLY CHAIN DEMANDS

A large number, and a wide range, of companies are involved in the marine renewable sector, and Figure 1 shows the key segments of the sector. However, as mentioned previously, few projects have progressed to the pre-commercialisation stage and so, as yet, there are few common strategies for procurement and contracting. Different members of the supply chain are responsible for different parts of projects depending on the type of project and its stage of development. Key classes of firms that are involved in the supply chain include Legal firms, Financial firms, Insurance firms, Marine Service firms, Technology Developers, Manufacturers, Test Facilities, Project Developers, Installation Contractors, and Energy Majors/Utilities (Scottish Enterprise document).

Focussing specifically on the manufacturing elements of the tidal supply chain, the Marine Action Plan (2010) states that "manufacturers and relevant supply chain companies need to move in as quick as possible to take the wave and tidal technologies forward to deployment scale, for example, by helping to develop the commoditisation of components, with opportunities taken where possible to build on the UK infrastructure being created to support offshore wind developments".

Work undertaken on the Pentland Firth and Orkney project (Crown Report, 2011) identify the key supply chain issue as being that of Operations and Maintenance. It states that logistics costs and response times are reduced by carrying out a large proportion of maintenance activities local to each project, thus using local port facilities. If port facilities were shared between projects and able to accept complete devices for repair or refurbishment, then the scale of activity could attract a supporting supply chain with a clustering effect. Although the procurement models for O&M services are yet to be fully developed, it is anticipated that in early years, core activities may be led by staff based locally and employed by device manufacturers. This will aid feedback of design improvements to improve next generation devices. As the industry matures, more third-party providers could be expected to enter the market. Even for early phases, it is anticipated that providers of vessels and onshore component refurbishment and repair will contract with the manufacturers of a number of different devices.

The MEC, 2011 identifies the key supply chain issue of the need to drive research in to lowering the costs of components in existing devices, by working with supply chain companies involved in component manufacture, including major components such as generators. These 'Strand B' projects as they are termed are R&D projects targeted at key cost areas in order to drive down the capital cost of tidal equipment.

Marine Renewable (Wave and Tidal) Opportunity Review (2005) identifies a wide range of supply chain activities that are required to bring a tidal supply chain project to fruition. The supply chain activities range from Legal firms, Financial firms, Insurance firms, Marine Service firms, Technology Developers, Manufacturers, Test Facilities, Project Developers, Installation Contractors, through to Energy Majors/Utilities. It is the effective integration and successful inter-linking of these supply chain elements that are critical to a successful implementation project. Figure 1 shows the key supply chain players.

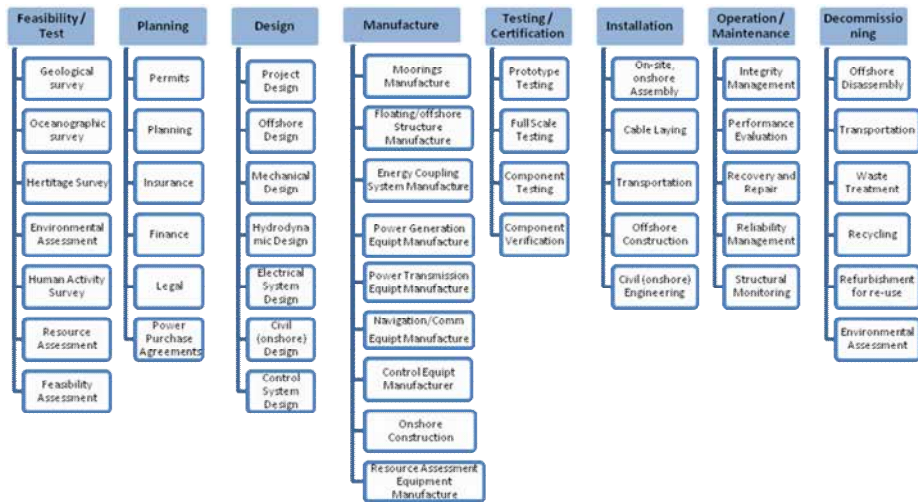


Figure 1: Segmentation of the Marine Renewable Sector (adapted from the Marine Renewable Opportunity Review (2005).

From the review of this literature, it is possible to identify four Supply chain clusters namely:

- R+D Supply Chain (Design, Development, Test & Certification, Prototyping)
- Manufacturing Supply Chain
- Maintenance Supply Chain
- Decommissioning Supply Chain

3.1 R+D Supply Chain

This is a highly mature area of development in the UK with a number of leading academic/industrial collaborative projects being undertaken across different energy sectors such as wind, tidal etc (SUPERGEN Wind, SUPERGEN Tidal etc). The main thrust of SUPERGEN is the development of highly efficient tidal technologies and whilst there is work undertaken in financial and economic analysis, little real work is undertaken within this project that directly tackles the supply chain issues surrounding tidal systems.

3.2 Manufacturing Supply Chain

As is typically seen with new technology based projects, the development of manufacturing supply chains that are capable of supporting the development and implementation of tidal projects is seen as relatively mature in areas of the UK where tidal projects have been implemented and continue to run (Pentland Firth and Orkneys, Wave Dragon Project, Wave Gen Inverness etc). The supply of specific tidal and wave modules is also relatively mature with companies such as Marine Current Turbines (Bristol) and Pelamic Waves Power (Edinburgh). The component manufacturers providing specialist equipment to these power units is also developing where there is a suggestion that most are centrally located in the North of England such as Bendalls Engineering in Carlisle, Hystat System Ltd, Huddersfield and a number of companies in Scotland providing large scale hydraulic components and systems.

What seems to be the case is that many of these companies have adapted their manufacturing capabilities and knowledge from the experience gained in working on previous large scale wind turbine technologies and oil/gas projects. The companies are embedded in the energy industry and have made a side ways step towards developing tidal and marine based technologies and systems.

What seems highly evident here though is the need for supply chain companies to collaborate closely with the energy companies and academic institutions who are developing the specifications and technical requirements of the technologies required for the implementation project.

3.3 Maintenance Supply Chain

It is here that the greatest possibility for local supply chain companies to take a stake in tidal and marine energy systems exists. Projects such as Pentland Firth are relatively large scale energy production sites and are now moving in to the need to service and maintain their turbine units following periods of productive outputs under water.

The Pentland Firth project identifies a clear 25 year design life for the turbines and a 5 yearly refurbishment and repair programme for each turbine unit thus creating a rolling programme of work for which a strong maintenance supply chain infrastructure must be in place to support such a programme. It is estimated that by 2024 that over 900 turbine units will require onshore repair with some 500 of those units requiring full refurbishment. By 2024 refurbishment is expected to become a significant component of maintenance activity provided that the reliability of devices has improved in line with estimates. It is anticipated that due to the amount of space required, a mix of local and more distant facilities will be used. The estimates assume that a mean time between failures of five years is achieved by 2030 through a gradual improvement in performance from first installations, where there is a much higher chance of unplanned failure. These assumptions are based on long- term targets for the industry but there is significant uncertainty in how these devices will operate in terms of failure rates, particularly in the early years after deployment. There will be a variation in performance between devices, individual project conditions and approaches taken by the project developers.

Whilst the vast majority of the maintenance work being undertaken by the suppliers of the technologies in the first instance, more open competition is likely to exist in the future where local contracts for maintenance and repair will be awarded. It is therefore clear that the maintenance, repair and overhaul of tidal energy technologies will provide significant opportunities to companies in the future.

3.4 Decommissioning Supply Chain

Although discussed in a number of key documents, there is little specific detail available as to what and how the decommissioning supply chain will work. As with the manufacturing and maintenance supply chains, it seems that the decommissioning supply chain may be initially dominated by the major tidal energy technology companies who will have the knowledge base to support dismantling and decommissioning. Some of the experimental tidal systems are now approaching their end of operational life and as such, the supply chains surrounding decommissioning will start to develop and mature. This is an area of research that will require close monitoring.

4 PROCUREMENT STRATEGIES

Since few projects have progressed beyond the stage of technology developer led programmes, common strategies for procurement and contracting for large projects are yet to emerge. However, it is evident from consultation with suppliers that there are a series of factors that are considered when selecting suppliers for involvement on a project (Court,2008).

- Companies need to be known to the technology developer (often just through contacts formed at conferences) , or have a reputation in the marine renewable sector
- Companies with industry-recognised experts are favoured, even if the area of expertise is not directly relevant to the activities expected of the company.
- Companies which are large enough to support or assist in the project through the provision of additional resources are also keenly sought after (e.g. large generator manufacturers who are willing to undertake additional research/development activities if needed).

Initially (i.e. during development stage), suppliers are hand picked by developers based on reputation, experience in the sector and personal contacts. At full scale, contracts are put out to tender,

with firms that are known to the developer or have an established reputation in the renewable sector being those that are invited to tender.

5 CONCLUSIONS AND FUTURE RESEARCH DIRECTION

Scant information currently exists on the development of tidal supply chain systems. Since much of the work is currently developmental, much of the supply chain development revolves around the technology companies and larger tidal manufacturing firms.

The UK supply chain seems well positioned to play a major role in the supply chain in two areas namely; the R+D supply chain and the maintenance supply chain. Significant work is being undertaken in the UK on the Research and Development of tidal systems whilst the potential for growth exists in the maintenance supply chain as tidal production facilities move from their experimental stage through to full production. Therefore, the need for advanced monitoring of tidal turbine performance is required and responsive and effective methods of maintaining tidal turbine systems both in-situ and on-shore will be required.

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ENGINEERING MANAGEMENT OF GAS TURBINE POWER PLANT CO₂ FOR MICROALGAE BIOFUEL PRODUCTION

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ABSTRACT

Fossil fuel accounts for over 80% of the world's primary energy, particularly in areas of transportation, manufacturing and domestic heating. However, depletion of fossil reserves, frequent threats to the security of fossil fuel supply, coupled with concerns over emissions of greenhouse gases associated with fossil fuel use has motivated research towards developing renewable and sustainable sources for energy fuels. Consequently, the use of microalgae culture to convert CO₂ from power plants flue gases into biomass that are readily converted into biofuel offers a window of opportunities to enhance, compliment or replace fossil- fuel-use. Interest in the use of microalgae biomass for biofuel production is high as it affords the potential for power plant CO₂ sequestration – (1kg of dry algae biomass uses about 1.83kg CO₂). Similarly, its capacity to utilise nutrients from a variety of wastewater, sets it apart from other biomass resources. These outlined benefits all emphasis the need for extended R&D efforts to advance commercial microalgae biofuel production. The paper is aimed at investigating the environmental performance of the microalgae biofuel production process using LCA.

Keywords: Microalgae biomass, Biofuels, Life Cycle Assessment (LCA).

1 INTRODUCTION

Microalgae biofuel production is an emerging field, which provides a new frame of opportunities as a potential alternative and sustainable energy derivable biomass resource. It has attracted a lot of attention, as a result of its potential to be converted into a variety of liquid and gaseous biofuels derivatives – using current technology & infrastructure. Nonetheless, algae cultivation, incorporation of production system for power plant flue gas use, biomass harvesting, oil extraction and biomass conversion processes have many challenges.

In this paper we present an integrated microalgae biofuel production model based on data available for algae bioprocess benchmarking optimization (Wijffels & Barbosa, 2010). The model (Fig. 1) is aimed at providing an articulate description of a possible wet and dry process route for biofuel production using the entire algae constituent biomass. The research work is distinctive in the sense that it integrates several different technical options of key algae biomass production and conversion pathways, power plant flue gas CO₂ use with regards to their Life Cycle Assessment (LCA) impacts. LCA results are cross-compared in order to identify the most significant opportunities for improvement with the final aim of developing a sustainable microalgae biofuel production model.

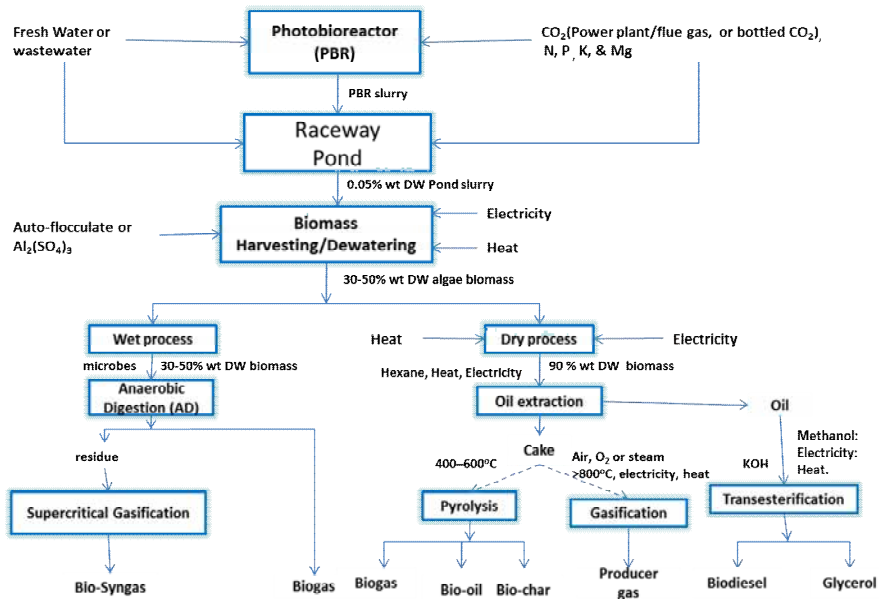


Figure 1: Wet & Dry Microalgae Biofuel Process Flow Diagram

2 METHODOLOGY

In the proposed framework (Figure 2), using LCA methodology entail the modelling of the full Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA) for each process unit of; microalgae cultivation, biomass harvesting/dewatering, and biomass oil extraction and conversion into biofuels. The LCI phase requires the computation of quantitative input/output data. While, the LCIA stage entail, determining and establishing the extent of impacts associated with the production process (Figure 2) in terms of; resource use, impact to human health and impact to the environment, using the ISO 14044 & CML 2002 guides respectively (Henrikke, B & Anne-Marie, T 2004).

Furthermore, parameters that affect production such as; Pond evaporation rate (PER), Algae growth rate (AGR) and lipid content (LC), Algae Recovery Rate after Harvest (RRH) and Slurry Content after Harvest (SCH), are factors which also affects the biofuel product composition ratio for each conversion technology, Energy efficiency of each conversion technology and process routes and Environmental emissions associated with each conversion process are analysed to evaluate their interactions, as understanding the burden of these parameters on the production process provides insight for advancing technology and reducing the impact of the overall energy use of future biofuel process (Yang et al., 2011).

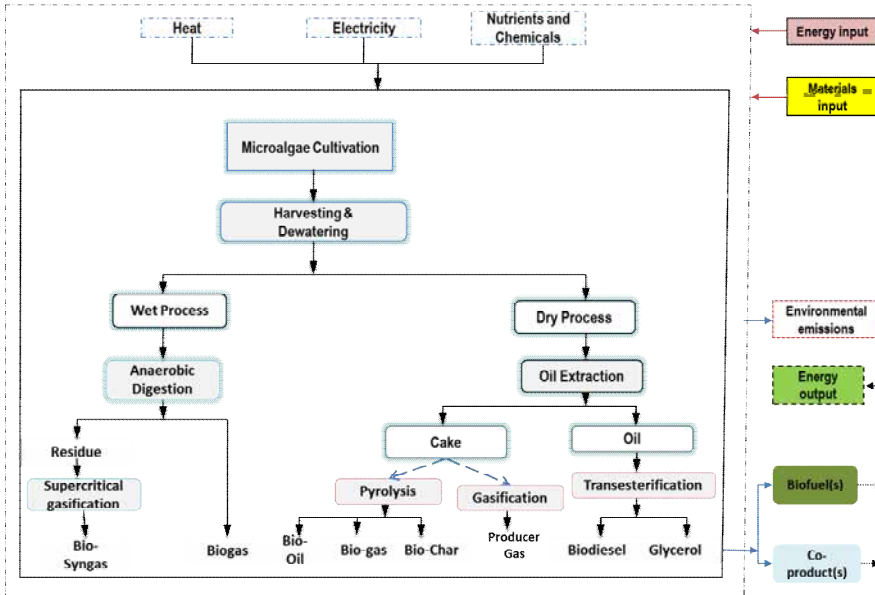


Figure 2: Microalgae biofuel production system boundary

The method proceeds with the interpretation stage, which highlights the significance and the strength of the evidence gotten and processed in previous stages. The interpretation phase entails drawing conclusions and articulating recommendations based on the findings from both the inventory analysis and impact assessment phases in line with the goal and scope of the study – which is to develop an energy/material efficient and environmentally sustainable model of producing biofuel using algae biomass – and in terms of total energy input, total energy output for the resultant biofuels and co-products, material resource use and environmental burden for the entire production process. Other important considerations are the functional unit (1MJ of biofuel), the choice of product/process alternative to be analysed, system boundary, how allocation issues are dealt with, formulation of the reference flow for each alternative process route option and the assumptions/limitations (Finnveden et al., 2009). These considerations help to ensure consistency of the LCA (Henrikke, B & Anne-Marie, T., 2004).

3 PRELIMINARY RESULTS

We found out that energy and CO₂ emissions drivers for the transesterification process includes; Energy consumed by Photo Bioreactor (PBR), hydraulic pumps for the open raceway pond, centrifuge, mechanical dryers, heating requirement to increase the biomass to 90% DWB (similar to that of soybean oil), fertilizer requirement, use of chemical flocculants, oil extraction processes and conversion techniques.

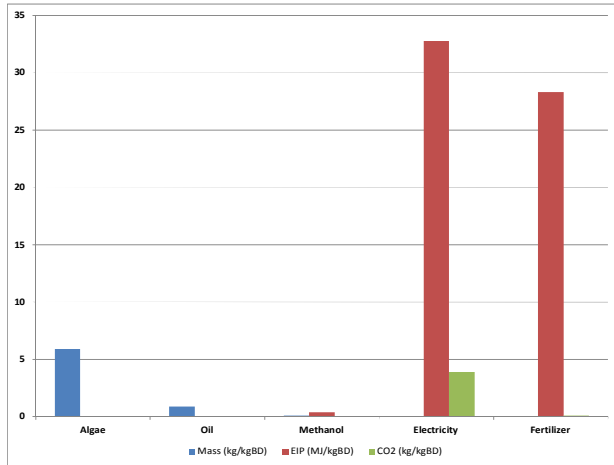


Figure 3: Production of 1Kg Biodiesel (BD): via Transesterification

Similarly, results indicate that heating to increase the biomass to 90% DWB accounts for 64% of total input energy from the transesterification energy input profile, while, electrical energy need and fertilizer requirement representing 19% and 16% respectively.

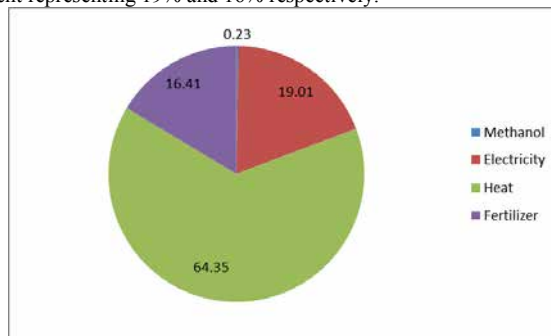


Figure 4: Transesterification Energy Input profile

Also, in our analysis of how the CO₂ gas transfer & mixing operations affects algae growth, we established that most power plants flue gas CO₂ concentration range between 10% - 15% (see Table 1), which are tolerable by most algae. However, when SO₂ levels exceed 400ppm in the flue gas, it lowers the pH – increases acidity. Conversely, there is need to assess and determine the Solubilities of combined flue gas components. As dissolved gases react together, new products are formed which may affect algae growth.

Table 1: Flue gas emission concentrations from different fuels Power Plants (Wang et al., 2008)

Emissions	Natural gas	Fuel oil	Coal
NO _x (ppm)	25-160	100-600	150-1000
SO _x (ppm)	≤0.5-20	200-2000	200-2000
CO ₂ (%)	5-12	12-14	10-15
O ₂ (%)	3-18	2-5	3-5
H ₂ O (%)	8-19	9-12	7-10

4 CONCLUSIONS

The LCA analysis methodology presented has been shown to be useful in providing insights into the economic and environmental performance of the proposed microalgae biofuel production system model. This is because it allows for; evaluating alternative pathways and identifying greater integration opportunities with greater economic advantage and lowering environmental burdens in relationship with existing models. The failure to date of previous models to consider the overall effect of process parameters has resulted in the inability to accurately predict product yields/environmental burdens with variations in operating conditions.

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Essam Shehab. Peter Ball. Benny Tjahjono Editors

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