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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 to 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 are 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. 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 the LeanPPD 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 statements have been developed based on the SBD principles and taking into account the elements which will characterise 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 industrial 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.

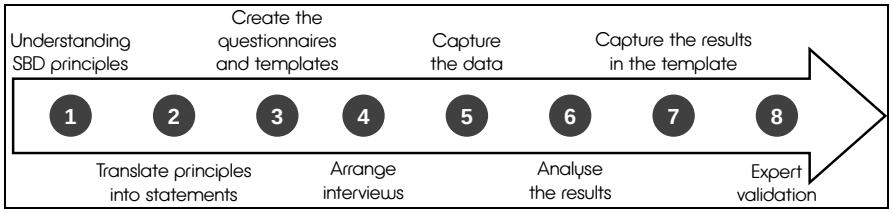


Figure 2: Industrial requirements elicitation process.

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 was a crucial step because it guaranteed a solid foundation for the industrial requirements' elicitation and further for the SBD model proposed. It is also very important to highlight that the statements have been organised according to the SBCE Baseline Model shown in Figure 1 to design a document that follows a clear logic and facilitates successful industrial interviews performing. Table 2, shows examples of how the captured principles have been converted into statements to elicit the SBD industrial requirements.

Table 1: Examples of SBCE principles and relative statements for the SBD process model.

SBCE Principles	**Relative industrial requirements statement**
Classify projects into a project portfolio (1.1 in Figure 1)	The SBD process model shall support the company's *project classification* process 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 (2.3 in Figure 1)	The SBD process model shall support the *'identification of feasible possibilities of the alternative design solutions' (map design space) based on: knowledge, experiences*, previous projects, and new innovative ideas. At the same time, considering constrains of different functional groups.
Pull innovative concepts from R&D departments (3.1 in Figure 1)	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.
Narrow sets gradually while increasing detail (4.6 in Figure 1)	The SBD process model shall facilitate activities to *aggressively narrow the set of solutions* into a reasonable number to be developed. These are also analysed based on certain criteria that address the identified value attributes.

One of the aims of the questionnaire was to capture how these requirements reflect the company needs to enhance their PD processes. Authors based the development of the measurement parameters on the good practices used to assess the requirements for the LeanPPD model (Al-Ashaab, 2010). Therefore three parameters to measure the importance and likelihood for introducing the requirement, as well as the possible constraints that might impede or prevent the introduction of it, were developed. To ensure that nothing important was missed, the 'other comments and suggestions' section was added for each requirement statement. Figure 3 presents an example of the structure for the questionnaire.

REQUIREMTN 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 parameters and their explanations used to assess the requirement are the following:

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 for interviewee to provide 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 constrains, 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.Req.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 characterise 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 key value 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.Req.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, competitors, 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.Req. 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 analysed 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.

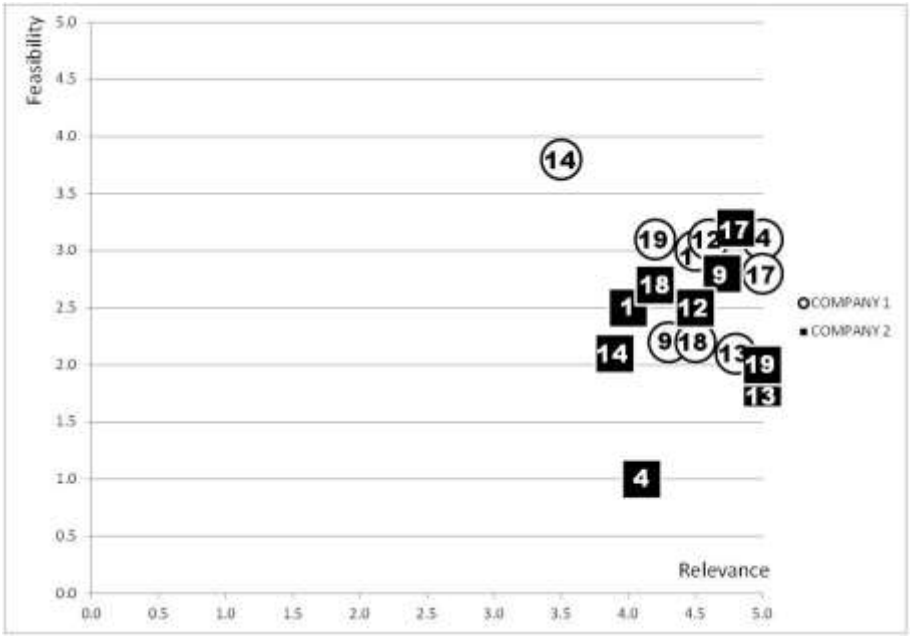


Figure 5: Example of Relevance-Feasibility Matrix

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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