Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 60 (2017) 350 – 355

www.elsevier.com/locate/procedia

27th CIRP Design 2017

The Set-based Concurrent Engineering application: a process of identifying the potential benefits in the Surface Jet Pump case study

Muhd Ikmal I. Bin Mohd Maulana[a], Ahmed Al-Ashaab[a]*, Jakub W. Flisiak[a], Zehra C. Araci[a], Piotr W. Lasisz[a], Essam Shehab[a], Najam Beg[b], Abdullah Rehman[b]

[a]*Cranfield University, College Road, Bedford MK43 0AH, United Kingdom*
[b]*Caltec Limited, Medway Court, Bedford MK43 0FQ, United Kingdom*

* Corresponding author. Tel.: +44-1234-750-111 x5622. *E-mail address:* a.al-ashaab@cranfield.ac.uk

Abstract

The Set-Based Concurrent Engineering (SBCE) is the methodology that can improve the efficiencies and effectiveness of product development. It is found that the SBCE approach provided a suitable knowledge environment to support decision making throughout the development process. This paper presents the potential tangible benefits gained from the application of the SBCE in an industrial case study of a Surface Jet Pump (SJP) that is used to revive the production of oil/gas from the dead wells. The well-structured SBCE process model and the process of identifying the potential benefits proposed in this paper will clarify the gap in the development of the SBCE in the company. The potential tangible benefits are established in a few key areas such as product innovation, product performance, manufacturing cost, and project success rate.

© 2017 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the scientific committee of the 27th CIRP Design Conference

Keywords: lean product development; set-based concurrent engineering; trade-off curves; creating knowledge; visual knowledge; oil and gas production; surface jet pump.

1. Introduction

Product development is important for company growth and success in business profitability. It is also used in the introduction of a variety of models, and most importantly. to keep the cost low. The demand for a quality, reliable product at an affordable price has put pressure on manufacturing companies to make a product that meets these criteria. It is impossible to make a transformation in product development without deliberating the current product development challenges [1] [2], which could be addressed by adopting Lean Product Development (LeanPD) and Set-based Concurrent Engineering (SBCE), for instance, in design rework, knowledge provision, and lack of innovation [3]. SBCE is a core enabler as it represents the method that guide the process of developing a product [4] [5], however, its constructive measure in real industrial applications is still ambiguous [6]. Thus, this paper aims to identify the potential benefits gained from the application of the details of SBCE process model in the SJP case study. The papers are structured into four sections, namely an introduction, a review of the SBCE related literature, SBCE case study, and SBCE potential benefits.

2. A review of the SBCE related literature

The literature emphasises on the importance of having SBCE in product development applications [3] [8] [9] [10]. This is because SBCE represents the definition of the process to be followed in order to develop a product. Toyota is famous for its production system, but it is commonly presumed that this is not the only factor of the success, because Toyota Product Development System

2212-8271 © 2017 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the scientific committee of the 27th CIRP Design Conference
doi:10.1016/j.procir.2017.01.026

(TPDS) is also playing an important role in this achievement [11]. Ward et al. [12] proved that the real success of Japanese manufacturers' is not derived from their production system, but from the TPDS. Later on, [10] shown a detailed description of the 13 principles that shaped the Toyota Product Development system. They provided a conceptual model called Lean Product Development System, which is divided into three subsystems: Process, Skilled People, Tools and Technology which entails of 13 principles.

SBCE is considered as the core enabler in Lean Product Development as it represents the process that guides the development of a product in a lean environment [16]. SBCE works on entirely different principles than point-based advance. A point-based design approach is the traditional PD practice where it only considers one best solution and later it is iteratively modified till it meets the acceptable result. The SBCE approach considers it desirable to develop various sets of solutions in parallel rather than working with one idea at a time. SBCE means; design participants practice SBCE by reasoning, developing, and communicating about a set of solutions in parallel. As the design progressed, they gradually narrow their respective set of solutions, based on the knowledge gained. As they narrow, they commit to staying within the sets so the others can rely on their communication [11].

Khan et al. [14] created the SBCE baseline model, consisting of five phases which are, 1) Define value, 2) Map design space, 3) Develop concept sets, 4) Converge on system, and 5) Detailed design, as illustrated in

Figure 1. In addition, [14] and [7] described the SBCE in a step-by-step process in the SBCE process model. This is to ensure the implementation is followed correctly at the first time, as illustrated in Figure 2.

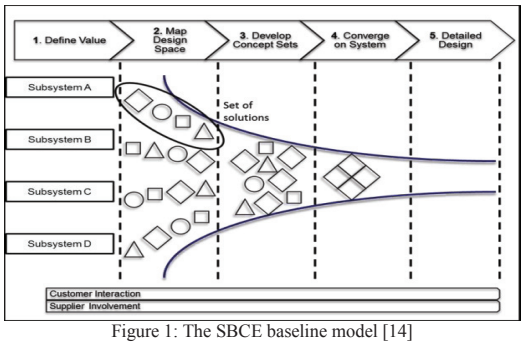

Figure 1: The SBCE baseline model [14]

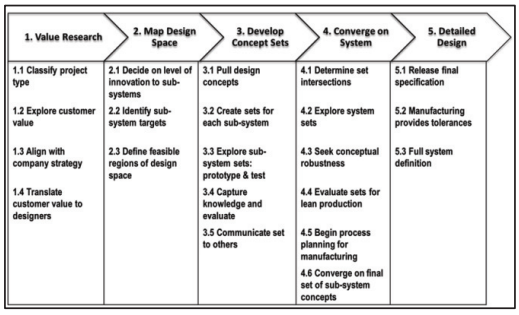

Figure 2: The SBCE process model [7] [14]

A limited number of SBCE case studies have been carried out in order to identify its potential and benefits to the industries [7] [15] [16]. However, there are no details of step-by-step application of the SBCE process model identifying the tangible benefits in the case studies where this paper will clarify the gap.

2. Industrial case study of a Surface Jet Pump (SJP)

The SBCE process model was implemented during the case study of SJP in collaboration with Caltec Ltd. The SJP as shown in Figure 3, is a device used to enhance productivity of oil or gas extraction in oil and gas wells by using the energy from a high pressure fluid/gas to boost the pressure of a low pressure from the wells. The following paragraphs present the selected activities of SBCE from Figure 2 that have been used in the case study.

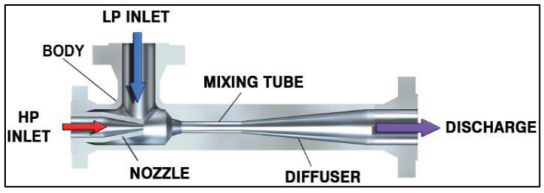

Figure 3: Cross-section view of SJP courtesy from Caltec Ltd.

Phase 1: Define Value

The initial concept of the SJP is defined in the Define Value stage, which has the subsequent SBCE activity.

1.2 Explore customer value

Customer needs must be clearly understood in order to identify the system targets, which focuses on the improvement of the SJP design performance. At first, Identified 38 values are listed and then the values are classified into a singular value which is cost, customization, design performance, manufacturability, reliability, durability, and installation as shows in Figure 4 section A.

Through the Analytical Hierarchy Process (AHP), values that have been classified as high importance were analysed [17], This led to define the key value attributes (KVA) as shown in Figure 4 section B where the 3 highest percentage were selected, these are; 1) Design Performance, 2) Manufacturability, 3) Cost and 4) Durability. In addition, cost was classified as KVA due to company's preference choice which has the major impact in the creation of this order. The values which remain (durability, reliability, customization, and installation) were assigned as values of consideration. The loads for the KVA in Figure 4 section B are calculated respectively by AHP value in Figure 4 section A. The result of the KVA are; 1) Design Performance; 38.5%, 2) Manufacturabilty; 37.5%, and 3) Cost; 24.0%

A

No	Value	AHP Priority (%)	Company Prioritisation
1	Cost	13.8%	3
2	Customisation	6.8%	6
3	Design Performance	22.3%	1
4	Manufacturability	21.6%	2
5	Reliability	15.7%	5
6	Durability	16.7%	4
7	Installation	3.1%	7

B

Key Value Attributes	Load of Importance
Design Performance	38.5%
Manufacturability	37.5%
Cost	24.0%

Values of consideration
Durability
Reliability
Customisation
Installation

Figure 4: The results of the SBCE activity of 1.2 "explore customer value"

KVA	System Target
Design performance	1) HP Pressure ≥ 400 psig 2) LP Pressure ≤ 205 psig 3) Discharge Pressure ≥ 320psig 4) The nozzle is replaceable 5) No moving parts 6) Smooth surface inside the mixing tube 7) Easy to change and install 8) Great production rate performance
Manufacturability	1) Low complexity 2) Fastest possible way to manufacture
Cost	1) Low manufacturing cost 2) Maintenance free

Table 1: System target for KVA in the SJP case study

In the next step, the system targets should be specified in order to explain how the value attributes will be reached. The system targets as depicted in Table 1, are measurable values which represent the target for the key value attributes.

Phase 2: Map Design Space

In this phase the scope of the design work as well as feasible regions of the SJP design was defined.

2.1 Decide on the level of innovation to the subsystem

In the activity 2.1 "Decide on the level of innovation to the subsystem", the SJP system structure was divided into subsystems as listed below and shown in Figure 5, these are; Flanges (1), Nozzle (2), Body (3), Mixing Tube (4), and Mounts (5). The level of innovation is a colour-coded tool that is used to visualise the level of innovation needed for subsystems of a product as illustrated in Figure 5.

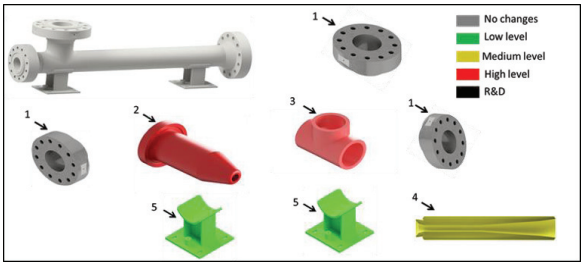

Figure 5: Level of innovations of the SJP subsystem

High level of innovation is required for the nozzle (2) and body (3). The nozzle (2) determines the performance of the system. The function of the body (3) is to provide a suitable flow direction for the fluids as well as to integrate each of the components in the SJP. The mixing tube (4) has been classified as a medium innovation. Mounts (5) are defined as "Low innovation" and Flanges (1) are coded as "no change in the design".

2.2 Identify subsystem target

In the activity 2.2 "Identify subsystem target", feasible targets for each subsystem is defined to prevent over engineering and supporting the development of innovation. The subsystem targets are listed correspondingly as presented in Table 2.

Subsystem	Subsystem Target
Nozzle	1) Nozzle are replaceable 2) Low complexity 3) Fastest possible to manufacture 4) No moving part 5) Maintenance free 6) Low manufacturing cost
Mixing tube	1) Easy to change and install 2) Ability to handle vibration 3) Smooth surface inside the mixing tube 4) Fastest possible to manufacture 5) Low complexity 6) Low manufacturing cost
Mount	1) Ability to absorb vibration
Body	1) Strong material type 2) Great production rate performance 3) Fastest possible to manufacture 4) Low complexity 5) Low manufacturing cost

Table 2 Subsystems target of the SJP

2.3 Define the feasible region of design space

In the activity 2.3 "Define the feasible region of design space", design space is defined as the boundaries for designers and engineers to explore and communicate with many alternative conceptual design solutions. Design space for the SJP and for the nozzle is presented in Figure 6.

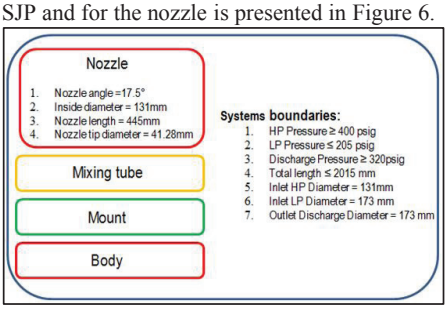

Figure 6 System and Subsystem boundaries

Phase 3: Develop Concept Sets

In phase 3, the sets of possible conceptual design solutions were developed for each SJP subsystem.

3.2 Create sets for each subsystem

In the activity 3.2 "Create sets for each subsystem", the alternative design solutions were generated. The following paragraph clarifies how the nozzle is designed and suggests possible conceptual design solutions as illustrated in Figure 7.

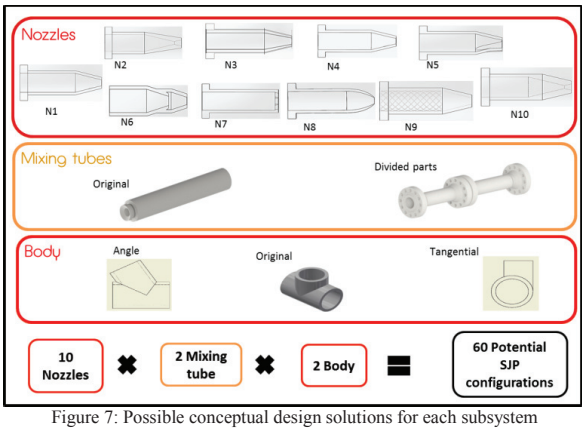

Figure 7: Possible conceptual design solutions for each subsystem

The subsystem targets are taken into account during generation of the alternative designs as listed in Table 2. In the next step, the defined boundaries have been considered in the SJP design process as depicted in Figure 6. As a result, set of 10 nozzle, 2 mixing tube, 3 body design concepts have been generated based on the creativity which corresponds to the key value attributes. The design space of the SJP could generate 60 potential systems as illustrated in Figure 7.

3.3 Explore subsystem sets: prototype & test

In activity 3.3 "Explore subsystem sets: prototype & test" , the conceptual solutions were evaluated. The analysis has been focused on the flow motion to determine the HP and LP values which give an impact to the performance of the SJP. The analyses were carried out for the nozzles by using the ANSYS CFX software as shows in Figure 8.

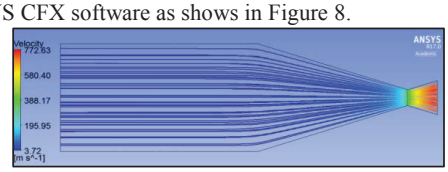

Figure 8: Example of CFD result for nozzle N10

The trade-off curves were used to narrow down the subsystem solutions based on the CFD simulation results, manufacturing complexity and manufacturing cost. These ToCs were generated together with consultancies from Caltec Ltd. The Trade-off Curves (ToCs) illustrated in Figure 9 show the reduction of solutions from 10 to 3 following designs which is the N2, N4, and N10. Since the nozzle design, N1 is the original design, it is excluded from the design set. As a result, the configuration has been reduced from 60 to 18, the calculation are as follows:

- 3 (nozzle) x 2 (mixing tube) x 1 (flange) x 3 (body) = 18.

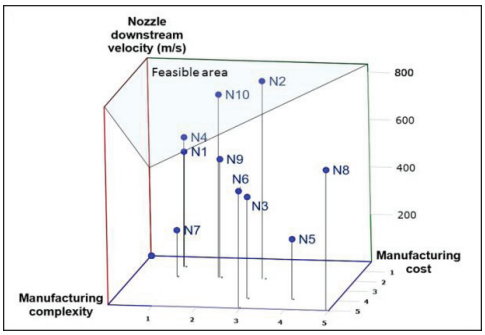

Figure 9: 3D ToC comparing and narrow down the solutions

Phase 4: Converge on Systems

To obtain the final optimum SJP design, alternatives which are not increasing the design performance were discarded and the rest of the possibilities have been developed until the optimum design solution was achieved.

4.1 Determine intersection of sets

In activity 4.1 "Determine intersections of set", the final designs of SJP systems were generated using feasible subsystem set of solutions. From 18 possible solutions, not all of them should be considered in the final analysis. Two techniques were used in parallel in activity 4.1 "Determine intersections of set" to narrow down the set of solutions which is; the CFD simulation of the SJP system as illustrated in Figure 10 and the ToCs as shows in Figure 11. As a result of the activity possible solutions were narrowed down from 18 to 3 which calculated as follows:

- 3 (nozzle) x 1 (mixing tube) x 1 (mount) x 1 (flange) x 1 (body) = 3

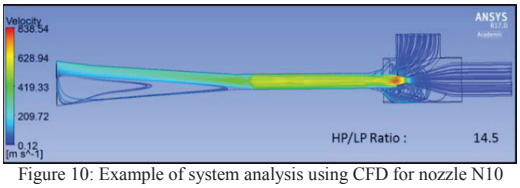

Figure 10: Example of system analysis using CFD for nozzle N10

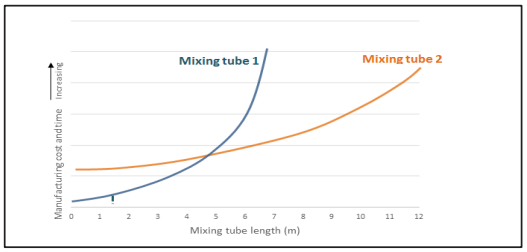

Figure 11: ToC for Mixing tube; Manufacturing cost and time vs. Length of mixing tube

4.6 Converge on final set of system

In activity 4 "Converge on final set of system", an aggressive narrowing process has been implemented based on the loads of importance from the KVA and ToCs which is design performance, manufacturability, and cost as depicted in Figure 9. The loads of importance weighted

technique were used to evaluate the final optimum solution as depicted in Figure 12. The scale (see Figure 12 section A) will later be multiplied with the loads of importance as shows in Figure 4 section B where the highest total of weightage will be selected as the optimal solution. These were made through a several brainstorming sessions within the research team based on the input from the manufacturer, CFD simulation and ToCs. As a result, the optimal solution of the SJP is N10 system which gives the highest score of 2.53 as depicted in Figure 12 section B. Thus, the solution will be released to the final specification in the detailed design on Phase 5 "Detailed design".

A

Scale	
4	The Best
3	Good
2	Moderate
1	The Worst

B

KVA	Loads of importance	N4	N10	N2
Design performance	38.5%	1	4	3
Manufacturability	37.5%	3	2	1
Cost	24.0%	3	1	1
Total Weightage		2.23	2.53	1.77

Figure 12: The loads of importance weighted based on the key value attributes (KVA)

Phase 5: Detailed Design

In this phase the final optimum solution of SJP system is presented. In this case study, only activity 5.1 "Release final specification" will be used.

5.1 Release final specification

In activity 5.1 "Release final specification", the final specification of SJP system design will be released. The final optimum solution N10 nozzle, original body and original mixing tube) is presented in technical drawing as shown in Figure 13. Due to confidentiality of data, the engineering drawing for the final optimum solution are given without any dimensions.

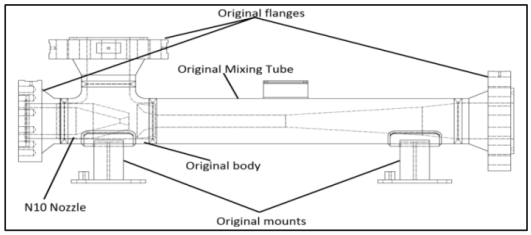

Figure 13: Engineering drawing of the final optimum solution for system (N10)

4. Discussion and conclusions

The SJP case study shows the detailed application of the SBCE process model in the real scenario. This case study has benefited the company, by enhancing its current product development process by providing a space to explore alternative designs from different angles i.e. product performance, manufacturability, and cost. Several tangible benefits were identified in the case study, which is product innovation, product performance, manufacturing cost, and project success rate.

First, the innovation and knowledge creation level has increased where 60 system design configurations were identified through the application of the SBCE process model in the case study as shows in Figure 7. The 60 system designs have been generated based on the creativity which corresponds to the key value attributes; Design performance, manufacturability, and cost. This will provide an opportunity for the designers and engineers in Caltec to explore various possible designs within the design space without having difficulty from the current product development practices.

Secondly, the product performance has been improved through an implementation of the SBCE. The improvement achieved in three areas which is velocity, pressure, and HP/LP ratio. These improvements have been gained through an analysis using ANSYS CFX simulation software for the subsystem (only for nozzle) and system. The result was based on the comparison between the N1 (original) design and the optimum solution, the N10. This analysis originated from the principle of Bernoulli in the fluid dynamics [18].

In order to run the ANSYS CFX simulations, two operating conditions are set which given by Caltec Limited. At first, a simulation is run for the nozzle to obtain the velocity of each nozzle. Then, the simulation is run for the complete system of the Surface Jet Pump (SJP) to obtain the pressure. The image of the simulations for the nozzle and the system are shown in Figure 14 and Figure 15;

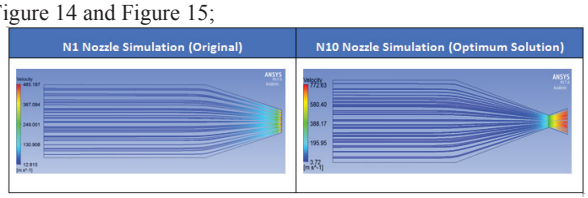

Figure 14: Ansys CFX simulation for Nozzles N1 and N10

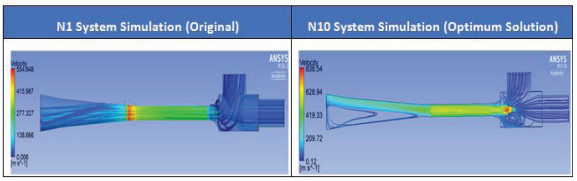

Figure 15: Ansys CFX simulation for system N1 and N10

The result of the ANSYS CFX simulation analysis is shown in Table 2 below:

No	System design	Nozzle outlet velocity (m/s)	Inlet LP Pressure (system) (psig)	HP/LP Pressure Ratio
1	N1 (Original)	485.187	283.34	1.9
2	N10 (Optimum solution)	772.627	170.63	14.5

Table 3 Ansys CFX simulation result comparison for system N1 and N10

From the result, the gas compressor suction pressure has been improved by increasing the nozzle performance velocity from 485.187 m/s in N1 design to 772.627 m/s in N10 design. This improvement creates a vacuum state at the tip of the nozzle which helps the gas to entrain the SJP system. Moreover, the LP pressure also simultaneously drops from 283.34 psi (N1 design) to 170.63 psig (N10 design), this gives an advantage for SJP to revive the dead oil well, hence it could further the production. The HP/LP ratio also has been increased from 1.9 to 14.5 which indicate the improvement of of the SJP in boosting the pressure of the LP gas entrained. The next

benefit gain from the application of the SBCE is the improvement of manufacturing cost. As Caltec Ltd is concerned about the manufacturing cost, the SBCE approach has been able to reduce the number of part changes by deciding the level of innovation (see Figure 5) for the subsystem of the SJP. The changes have been made only for the nozzle while other subsystems remain same as the current design. This involves a minor change which is associated to one additional operation – a turning process of 35mm deep from the tip of the nozzle. As refered to the Caltec Ltd. manufacturer, Woodfield System Ltd., the additional process will use the same existing tools, hence no extra cost incurred in the manufacturing. The manufacturer also stresses that there is no additional time to fabricate the N10 nozzle compared to previous. Due to the confidential issue, the manufacturing cost is based on the estimated cost which is £610.31 including the cost of the material. This means that the cost of the N10 nozzle design is the same compared to the original N1 nozzle, however, the performance is significantly improved.

The probability of having a successful project has also been increased by implementing the SBCE in the product development. According to [8], three rules were implied in the probability to identify the risk;

1. The probability of failure is one minus the probability of success and vice versa.
2. The probability of a number of independent events happening at the same time is the product of the individual probabilities.
3. The average number of occurrences of an event in a series of trials is the probability of occurrence in each trial, times the number of trials.

In the probability test, the comparison was made between three final possible solutions from the SBCE approach and one solution in traditional point-based design approach. The three final possible solutions were taken from the activity 4.1 "Determine intersections of set" as each of the subsystems at this stage has a potential to integrate to each other. Meanwhile, the one solution is taken from the current practice of product development in the company. From the probability tests, the success rate has increased to 96%, which average of 2.4 successful designs compared to 33% with the average only 0.8 successful designs – not even 1. This result shows how SBCE approach is much more reliable compared to point-based approach. In addition, the risk of having a failure design also has been reduced from 20 % to 0.8 % after SBCE application. As summarised, the research proves that the SBCE has the potential to produce high quality products on time and in a cost effective manner.The case study is limited to the application of the SBCE in SJP at Caltec Ltd. Future work may consider a development of the business case in SBCE application. This could enhance the SBCE process model, reaching the level of "business oriented" which significantly reflects company performance. The achievement can then be tracked and measured in order to deliver an accurate solution to the company.

Acknowledgements

The authors would like to thank to all researchers of the LeanPPD research group in Cranfield University. Also, we would like to thank Majlis Amanah Rakyat (MARA) for sponsoring the Ph.D of the first author. Finally, the authors wish to thank to Caltec Ltd (Cranfield, UK) for its continuous support in this research.

References

[1] Curwen LG, Park J, Sarkar AK. Challenges and Solutions of Sustainable Apparel Product Development: A Case Study of Eileen Fisher. Cloth Text Res J 2013;31:32–47.

[2] Cooper LP. A research agenda to reduce risk in new product development through knowledge management: a practitioner perspective. J Eng Technol Manag 2003;20:117–40. doi:10.1016/S0923-4748(03)00007-9.

[3] M. S. Khan, A. Al-Ashaab, E. Shehab, B. Haque, P. Ewers, M. Sorli, and A. Sopelana, "Towards lean product and process development," Int. J. Comput. Integr. Manuf., vol. 26, no. 12, pp. 1105–1116, 2013.

[4] Al-Ashaab A, Golob M, Urrutia UA, Gourdin M, Petritsch C, Summers M, et al. Development and application of lean product development performance measurement tool. Int J Computer Integrated Manufacturing 2015;29:342–54. doi:10.1080/0951192X.2015.1066858.

[5] Sobek DK, Ward AC, Liker JK. Toyota's principles of set-based concurrent engineering. Sloan Manage Rev 1999;40:67–84.

[6] Khan M. The construction of a model for Lean Product Development tle. Cranfield University, 2012.

[7] A. Al-Ashaab, M., Golob, U. M., Attia, M., Khan, A., Andino, A., Perez, P., Guzman, A., Onecha, S., Kesavamoorthy, G., Martinez, E., Shehab, J., Parsons, A., Berkes, B., Haque, M., Soril, and A., Sopelana, "The transformation of product development process into lean environment using set-based concurrent engineering: A case study from an aerospace industry," Concurr. Eng. Res. Appl., vol. 21, no. 4, pp. 268–285, 2013.

[8] A. C. Ward and D. K. Sobek II, Lean product and process development, 2nd ed. Lean Enterprise Institute, Inc., 2014.

[9] M. Kennedy, Ready, set, dominate : implement Toyota's set-based learning for developing products and nobody can catch you. The Oaklea Press, Richmod, Virginia, 2008.

[10] J. Morgan and J. Liker, The Toyota Product Development System, Integrating People, Process, and Technology, vol. 1. New York, USA: Productivity Press, 2006.

[11] D. K. Sobek, A. C. Ward, and J. K. Liker, "Toyota's principles of set-based concurrent engineering," Sloan Manage. Rev., vol. 40, no. 2, pp. 67–84, 1999.

[12] A. Ward, J. K. Liker, J. J. Cristiano, and D. K. Sobek, "The second Toyota paradox: How delaying decisions can make better cars faster," Sloan Manage. Rev., vol. 36, pp. 43-43, Journal Article, 1995.

[13] A. Al-Ashaab, M. Golob, U. A. Urrutia, M. Gourdin, C. Petritsch, M. Summers, and A. El-Nounu, "Development and application of lean product development performance measurement tool," Int. J. Comput. Integr. Manuf., vol. 29, no. 3, pp. 342–354, 2016.

[14] M. Khan, A. Al-Ashaab, A. Doultsinou, E. Shehab, P. Ewers, and R. Sulowski, Set-Based Concurrent Engineering process within the LeanPPD environment. 2011.

[15] K. Madhavan, D. Shahan, C. C. Seepersad, D. A. Hlavinka, and W. Benson, "An Industrial Trial of a Set-Based Approach to Collaborative Design," ASME 2008 Int. Des. Eng. Tech. Concferences Comput. Inf. Eng. Conf., pp. 1–11, 2008.

[16] D. Raudberget, "Practical Applications of Set-Based Concurrent Engineering in Industry," Strojniški Vestn. - J. Mech. Eng., vol. 56, no. 11, pp. 685–695, 2010.

[17] N. Bhushan and K. Rai, Strategic Decision Making: Applying the Analytic Hierarchy Process. Springer Science & Business Media, 2007.

[18] Munson, B.R., Young, D.F. and Okiishi, T.H., 1990. Fundamentals of fluid mechanics. New York, 3(4).

https://dspace.org/

The set-based concurrent engineering application: a process of identifying the potential benefits in the surface jet pump case study

Mohd Maulana, Muhd Ikmal I. Bin; Al-Ashaab, Ahmed; Flisiak, Jakub W.; Araci, Zehra Canan; Lasisz, Piotr W. ...

2017-05-09
Elsevier
https://dspace.lib.cranfield.ac.uk/handle/1826/11949
Maulana MI, Al-Ashaab A, Flisiak JW, et al., (2017) The set-based concurrent engineering application: a process of identifying the potential benefits in the surface jet pump case study. Procedia CIRP, Volume 60, 2017, pp. 350-355

Downloaded from a DSpace repository. https://dspace.org/