Developing Business Case Framework For The Introduction Of The Set-Based Concurrent Engineering; A Case Study At Jaguar Land Rover

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***Abstract*—**Product development challenges have put such an immense pressure to companies like Jaguar Land Rover (JLR) to become more competitive and efficient in the market. The key demand is sustaining the design through product innovation, produce a quality product, shorten the lead time and in a cost effective manner. Lean Product Development (LeanPD) through the Set-Based Concurrent Engineering (SBCE) is an approach that has these capabilities including providing a suitable knowledge environment to support decision making throughout the development process. This paper presents a process of developing a business case framework (SBCE-BC) for the introduction and application of the SBCE principles to justify its effectiveness. The structure of the SBCE-BC framework proposed at the end of this paper presents a generic guideline of having a business case in SBCE by justifying the benefits of its application. The framework was established based on the LeanPD application study at Jaguar Land Rover (JLR).

***Keywords*—**Business case, Lean product development, Set-based Concurrent Engineering, Lean thinking.

I. Introduction

THE increasing need for continuous product innovation in the global market forces companies to improve their business strategy using lean approaches in their product development. This ensures their survival by producing better quality and reliable products at an affordable price. However, it is impossible to make the lean transformation without deliberating on 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]. The SBCE is a core enabler of Lean Product Development as it represents the method that guide the process of developing a product [4][5]. SBCE provides an environment where the design space is explored thoroughly which leads to enhanced innovation. This is done by considering an alternative set of solutions after gaining the knowledge to narrow down the solutions until the optimal solution is reached. However, the successful measures of the SBCE applications in practice are still ambiguous. To overcome this, the author believed that having a business case is the way to demonstrate and justify the benefits comes from the application of the SBCE. The propose of four-phase SBCE-BC framework has been established based on the analysis of the introduction of the LeanPD application at the JLR Chassis Engineering Department via assessment study and case study. The process of developing the framework could significantly facilitate the justification of the SBCE benefits, hence improve the needs of having the SBCE in the company. The paper is structured into eight sections namely; I) Introduction, II) The Literature, III) SBCE in the business context of JLR, IV) SBCE applications: Brake Pedal case study, V) The benefits of the SBCE in Brake Pedal case study, and VI) Result and conclusion.

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II. The literature

A. A review of Set-Based Concurrent Engineering

Ward [6] discovered that the real success of Japanese manufacturers' originated from the Toyota Product Development System rather than their production system. Ward found this through investigating multiple alternative solutions during the styling activity rather than deciding to pursue one solution. Sobek [5] put the following definition forward: design participants practice SBCE by reasoning, developing, and communicating about a set of solutions in parallel. As the design progresses, they gradually narrow down their respective set of solutions based on the knowledge gained. As they narrow, they commit to staying within the sets so that the others can rely on their communication. In contrary, the point-based design approach works entirely different than SBCE. A point-based design approach is the traditional product development practice where it only considers only one best solution and it is iteratively modified till it meets the acceptable result [5]. However, [7] [8] discovered that the iterations could be very expensive and takes a lot of time to reach the final solution as well as there is no guarantee that the iteration process will end up with the generation of the optimum solution. SBCE approach allows to handle various sources of uncertainties during early stages of product development and make well founded decisions which significantly reduces the need for iteration process [5]. SBCE emphasis three essential values such as exploration of design space, communication between interdependent groups, and delayed commitment until a feasible solution is achieved. Thus, the SBCE approach considers it desirable to develop various sets of solutions in parallel rather than working with one idea at one time.

The principle of SBCE was described in the conceptual framework which breaks into three broad principles; map the design space; integrate by intersection; and establish feasibility before commitment [5]. Morgan and Liker [9] stressed that SBCE is significant as it became part of the Toyota product development system under the principle of “front-load the product development process to explore thoroughly alternative solution while there is maximum design space”. They also pointed out that Toyota used the trade-off curves and decision matrices to communicate and evaluate set of design solutions. However, they have not provided a detailed SBCE process model.

Khan [10] 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 designs, as illustrated in Figure 1.

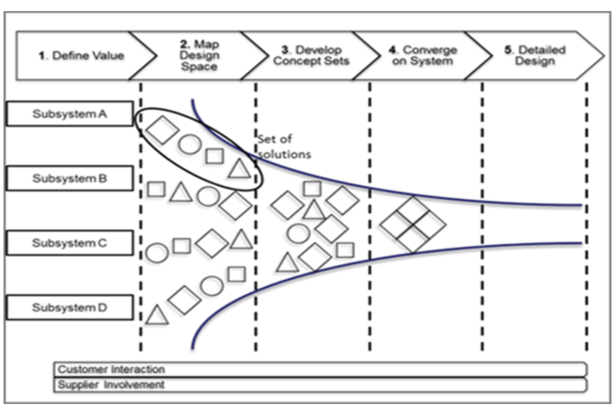

Fig. 1 SBCE Baseline Model

In addition, [10] [11] 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.

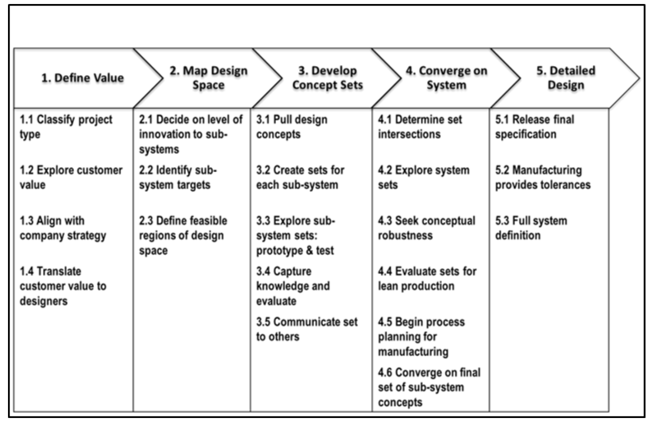

Fig. 2 The SBCE process model

B. Business case overview

Literature review regarding business case is explained in this section. Harvard Business School described a business case as a tool for identifying and comparing multiple alternatives for pursuing an opportunity and then proposing the one course of action that will create the most value [12]. Harvard Business School also described developing a business case in seven steps which is; 1) Define the opportunity, 2) Identify the alternatives, 3) Gather data and estimate time frame, 4) Analyse the alternatives, 5) Make a choice and assess the risk, 6) Create a plan for implementing an idea, and 7) Communicate the case to get recommendations from decision makers.

Literature also defined business case as a structured document which is supported by an analysis of its cost, benefits and risk [13]. The business case contains a specific requirement by considering the situational-gathering to justify the measurable benefit; hence the benefits serve as communication tools [14]. These could be in the form of spreadsheet, presentation, document or explanatory articles [15]. Ward [16] mentioned that 67 % of the European companies surveyed are convinced that business case is important in order to increase the value of an investment. In addition, the business case should be defined in an objective way and can be assessed in term of the benefit delivered [16].

Robinson [17] develop a business case framework for knowledge management called IMPakt. They developed the framework using a three pronged approach which consists of questionnaire surveys, semi-structured interviews, case studies, and industrial workshops. The frameworks have three stages where the outcome is explained as follows; Stage 1: Understand the challenges in the current organisation; Stage 2: Clarifies the challenges and develop a specific plan to address the challenges; and Stage 3: Evaluate the impact of the selected solution by providing a justification of the tangible and intangible benefits.

III. SBCE IN THE BUSINESS CONTEXT OF JLR.

This section explains the first phase of the proposed business case framework of SBCE mentioned in Figure 13. The work is based on the case study at Jaguar Land Rover

(JLR), United Kingdom. At first, an initial study to introduce LeanPD was conducted in eight functions of the Chassis Engineering Department. The purpose of the field study is to understand the current PD practices and identify the current PD challenges facing the company. Two methods were employed in this phase, which are: 1) SMART LeanPD Assessment tool [4], and 2) Semi-Structured Interviews. The findings in the field study were used to develop a business case which will set the next stages for introducing and implementing LeanPD and the principles of Set-Based Concurrent Engineering (SBCE) at JLR.

A. SMART LeanPD Performance Measurement Tool

The LeanPD SMART Assessment Tool enables the tracking of the Lean Product Development journey of a company. It allows an assessment of the current Product Development practices against best practices and principles of LeanPD on a SMART scale (Start, Motivate, Apply, Review and Transform) as shown in Figure 3. The study used the Lean-PPD SMART Assessment tool consisting of four perspectives: 1) Product Development (PD) Process, 2) Tools and Methods, 3) Knowledge, 4) People and Skills. Each perspective has ten questions where each question has five possible statements to choose from, which are not covered in this paper. The statements range from the lowest Lean Product Development level to the highest based upon a "SMART" scale of 1-5 as displayed Figure 3.

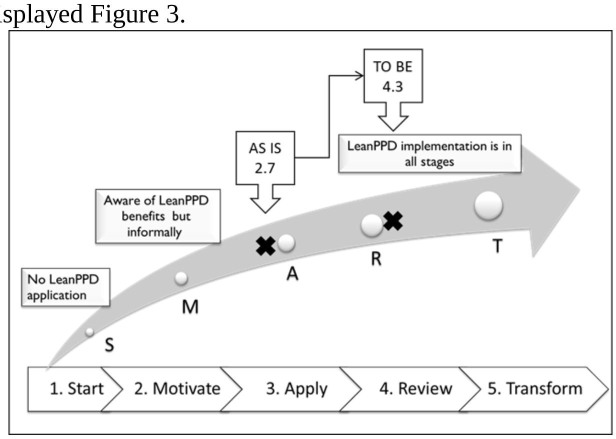

Fig. 3 Overall result of the Lean-PPD performance assessment of the Chassis Engineering Department at JLR

A total of 74 employees from JLR participated in the study, in which they answered the questions individually. The participants came from the 8 functions within the Chassis Engineering Department which is; 1) Suspension Systems Integration, 2) Suspension Systems Architecture, 3) Steering Wheels & Tyres, 4) Suspension Systems Tuning, 5) Driving Dynamics, 6) Brakes Design, 7) Business and Programmes, 8) Motion Control. The results from each section of the assessment have also been analysed independently of each other to look at the results of each question in more detail. A summary of the finding explains below.

Results from the assessment reveals an overall score of '2.7' for the current AS-IS Lean Product Development practices in JLR, and a score of '4.3' for the desired TO-BE practices. In summary, the current lean practices are close to the level 3 (Apply) on the SMART scale of the Lean-PPD Performance Measurement Tool. This means the company is aware of some LeanPD practices and is already doing some lean implementation, but not comprehensively. Furthermore, this means the current lean applications are used in certain activities within the different projects in product development. The 'TO-BE' score is 4.3 indicates the common view of a desire to formally implement lean practices in product development processes.

B. Semi-structured Questionnaire Results

To verify the findings from the Performance Assessment, a face-to-face interview was conducted with 44 respondents. This section summarises the findings of the face-to-face interviews on the PD practices within the Chassis Engineering Department of Jaguar Land Rover. The group of employees that underwent the questionnaire was chosen from the sample of 83 employees that participated in the performance assessment. The main criteria for the selection was the diversity of roles, responsibilities and experience within the function, in order to obtain representative and comprehensive results; as well as the motivation and willingness of the individuals to cooperate and offer extra information during the mentioned Performance Assessment. The main focus of the Semi-structured Questionnaire was to identify the current product development challenges in the department, with a focus on findings from the SMART performance assessment. From the data analysis of results obtained, 3 key challenges were identified which explained in Table 1.

No.	Challenges	Descriptions
1	Design Rework	• The concept of late change is wrong within the department, as it is viewed negatively. This means design changes are currently viewed as rework rather than an iterative process
2	Product not meeting the specification	• Most of the time, the concept phase is not given so much attention because of the pressure to meet targets. This eventually leads to design reworks and quality issue.
3	Creativity and Innovation	• Lack of exploring possible design solutions at the design phase hinders creativity and innovation of design parts

Table 1 Key PD challenges from performance assessment and face-to-face interviews

To address these challenges, a pilot project on a brake pedal box was selected to demonstrate the ability of SBCE within a lean environment in addressing the challenges faced by the company. The brake pedal box pilot project is explained in the next section.

IV. SBCE Applications: Brake Pedal Case Study

The SBCE process model was applied in a case study to demonstrate its ability in solving the product development challenges faced by the Chassis Engineering Department at JLR. This section explains the detailed process for phase 2 and 3 in the proposed framework as illustrated in Figure 13. The PD challenges mentioned earlier was identified during the performance measurement study and face-to-face interview phase of the project. Sensitive information has been deleted or modified during the project to keep in line with the Non

Disclosure Agreement that was signed with the company. The brake pedal box is one of the most important parts in a car which functions to assist a car driver to have control over the car while driving. Figure 4 shows the elements of the brake pedal box: 1) Bracket, 2) Pedal arm, 3) Pedal Pad 4) Bushing

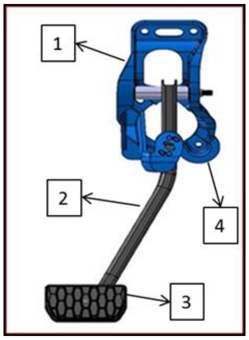

Fig. 4 The system level of brake pedal box

The most important characteristics of the brake pedal box desired are safety, reliability, and stiffness of the brake pedal box. The SBCE however, has a set of activities that must be carried out to validate its benefits to the PD process. These step-by-step SBCE activities have been listed earlier in Figure 2. Due to availability of time to carry out the case study and the complexity of the product, not all of the SBCE activities were implemented. The next paragraphs explain the selected activities of the SBCE process model of the case study.

Phase 1: Define Value

1.1 Explore Customer Value

The aim of this case study is to find an improved design of a brake pedal box applying the principles of SBCE. To do so, following the process model of the mentioned approach, the value attributes for the assembly must be identified. A first list of 25 value attributes was generated through brainstorming, analysing the customer requirement documents and interviewing the personnel in charge of the brake pedal box. A total of 25 values attributes was then classified into 10 categories for easier handling of the analysis. For example, these five (5,6,7,9,10) values were classified as a single value attributes tagged ‘Stiffness’. In this same way, the rest of the values were classified based on the similarity of their objectives. Furthermore, to identify the most relevant attributes for the assembly, the loads of importance of each of them had to be evaluated and compared with the rest. This was achieved using the Analytic Hierarchy Process (AHP) [18][19] matrix which is not covered in this paper. The AHP matrix helps to identify the relevance of each value attribute for the pedal brake box. Additionally, since the design cannot be based on all the value attributes, the top three designs with the highest relevance scores were chosen which are; 1) Stiffness-, 2) Safety, and 3) Durability as depicted in Table 2-A. Finally, the loads of importance are calculated respectively by the AHP value in Table 2-B. The result of the key value attributies (KVA) are; 1) Safety; 39%, 2) Reliability; 35%, and 3) Stiffness; 26%.

A

No	Value	AHP Priority (%)
1	Feeling	7%
2	**Stiffness**	**14%**
3	**Safety**	**22%**
4	Manufacturability	6%
5	Weight	3%
6	Aesthetics	1%
7	Packaging	6%
8	Ergonomics	8%
9	**Reliability**	**19%**
10	Cost	14%

B

KVA	Load of importance
Safety	39%
Reliability	35%
Stiffness	26%

Table 2: The result of the SBCE activity of 1.2 “Explore customer value”

Other values had low loads of importance because of several reasons, but most importantly, because they was no need to make improvements on them. Moreover, the system targets also should be specified at this phase in order to explain how the KVA will be reached. The system targets are measureable values which represent the target for the key value attributes as illustrated in Table 3.

No	Customer value	System targets
1	Safety	1. The pedal box has to pass a life cycle test 2. The pedal box has to pass a structural test 3. The pedal box has to pass a lateral detection test 4. The pedal box has to pass a pedal free swing test 5. The pedal box has to pass a reverse overload test 6. The pedal box has to pass a drop test
2	Reliability	1. It has to last for at least 100,000 miles or more 2. Temperature operation range has to be -30C 3. No defects or excessive wear permitted
3	Stiffness	1. Pedal arm has to be at an angle of 30 to 35mm 2. The pedal box has to resist a maximum perpendicular load of 2kN 3. The pedal box has to pass a life cycle test 4. The pedal box has to pass a structural test 5. The pedal box has to pass a lateral detection test 6. The pedal box has to pass a pedal free swing test 7. The pedal box has to pass a reverse overload test 8. The pedal box has to pass a drop test

Table 3: System Target for KVA in brake pedal case study

Phase 2: Map Design Space

2.1 Decide on Level of Innovation

Each of the components of the brake pedal box was analysed individually and it was decided whether it is worth developing them and to what level. The Level of Innovation tool is a colour coded tool which is used to simply communicate the innovation levels: providing the scale of levels of innovation considered. Figure 5 below illustrates an engineering drawing of the brake pedal box assembly, identifying the components and their respective level of innovation. A high level of the innovation (red colour coded) was required for the bracket since there was a lot of flexibility in its design in terms of geometry and material. Furthermore, medium level of innovation (yellow colour coded) was required for the pedal arm while the pedal pad and bushing are needed “no changes” in the design.

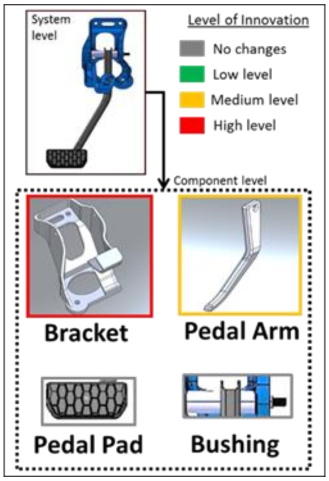

Fig. 5 Level of innovation

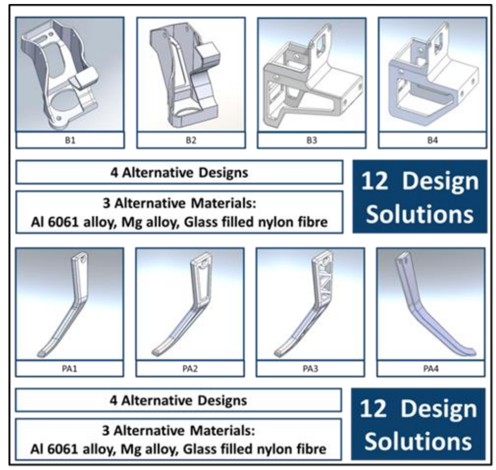

Fig. 6 Possible design solutions

2.3 Define Feasible Regions of Design Space

To have clear objectives for the design and then to evaluate those different design alternatives, it was important to define feasible regions. Defining the feasible regions of design space also helps to reduce waste caused by over-engineering. Some characteristics and targets have been decided based on the given specifications document and the tests which will be carried out. The targets set for the different elements will determine several feasible regions for several characteristics, these are shown in Table 4.

Component	Boundaries	Value
Bracket	Max. Cost material Max. Weight Min. Factor of safety Von Mises stress	£ 2.00 500 g 2 1 x 10^3 Nm^{-2}
Pedal Arm	Max. cost material Max. Weight Min. Factor of safety Von Mises stress	£ 2.50 800 g 2 4 x 10^4 Nm^{-2}

Table 4 Component boundaries

Phase 3: Develop Concept Sets

3.1 Extract Design Concepts

A small research of existing designs and different design approaches was performed to inspire the generation of alternatives for the different components. Given the time constraints of this project, all the efforts were put forward in the creation of alternative designs for the bracket and the pedal arm. Provided sufficient time for it, the same process would be followed for pulling and further exploring different designs for the bushing.

3.2 Create Sub-Systems Sets

As described in Figure 6, four designs were found for both the bracket and the pedal arm; and three different materials were considered for each of them. This gives a total of 4x3=12 possible designs for each of them. When combined, it gives a total of 144 (12x12=144) different possible designs solutions for the brake pedal, and therefore, potential solutions.

3.3 Explore Sub-Systems Sets: Prototype and Test

The purpose of this activity is to analyse the conceptual solutions to ascertain their reliability. The simulation analysis in Solidworks software was used to create virtual prototypes of the parts that had the desired level of innovation i.e. the bracket and pedal arm. The stress analysis and factor of safety test analysis were carried out for the bracket (4 alternative designs) and pedal arm (4 alternative designs) as shown in Figure 6. The tests for both component alternatives design use three different alternative materials which is Aluminium Alloy 6061, Magnesium Alloy, and Glass filled nylon fibre. These materials were selected due to their characteristic ability to address the KVA which is safety, reliability, and stiffness. With 4 alternative designs combining with 3 material selection for bracket and pedal arm, a 144 possible design solution were generated and the calculation as follows: [4 (bracket) x 3 (material)] + [4(pedal arm) x 3 (material)] = 144 possible solutions. Due to the low complexity of the design of the components, the team agreed to simulate all the possible solutions to generate the stress and factor of safety values as shows in Figure 7.

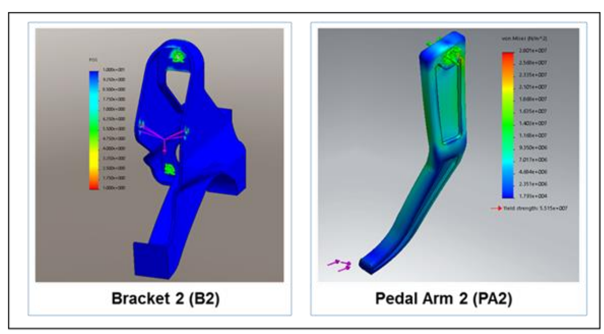

Fig. 7 Example of the simulation analysis using Aluminium Alloy 6061

From the result of the simulation, the trade-off curves (ToCs) were used to aggressively narrow down the solutions [20]. The ToCs were generated based on the component target in Table 4 which is stress, factor of safety, material cost, and weight. The stress values and factor of safety value were gathered from the simulation data while the material weight and cost data are calculated using weight and cost of material equation. Figure 8 illustrates the ToCs for the bracket. In this stage, the focus is to identify the component that could satisfy each of the ToCs values. A combination that does not satisfy any of the ToCs will be discarded. For instance, bracket "2.3" has a perfect relation as the values of stress (Figure 8-A), factor of safety (Figure 8-B), and material cost and weight (Figure 8-C) are within the feasible area in the ToCs. Contrary is the bracket "1.1", where not all values are within the feasible area in the ToCs- hence, it will be discarded from the list of solutions. Similarly the rest of the bracket and pedal arm were evaluated with the same method. As the result, the configuration was reduced from 144 to 6. The calculation is below:

- 2 (bracket) x 3 (pedal arm) x 1 (pedal pad) x 1 (bushing) = 6

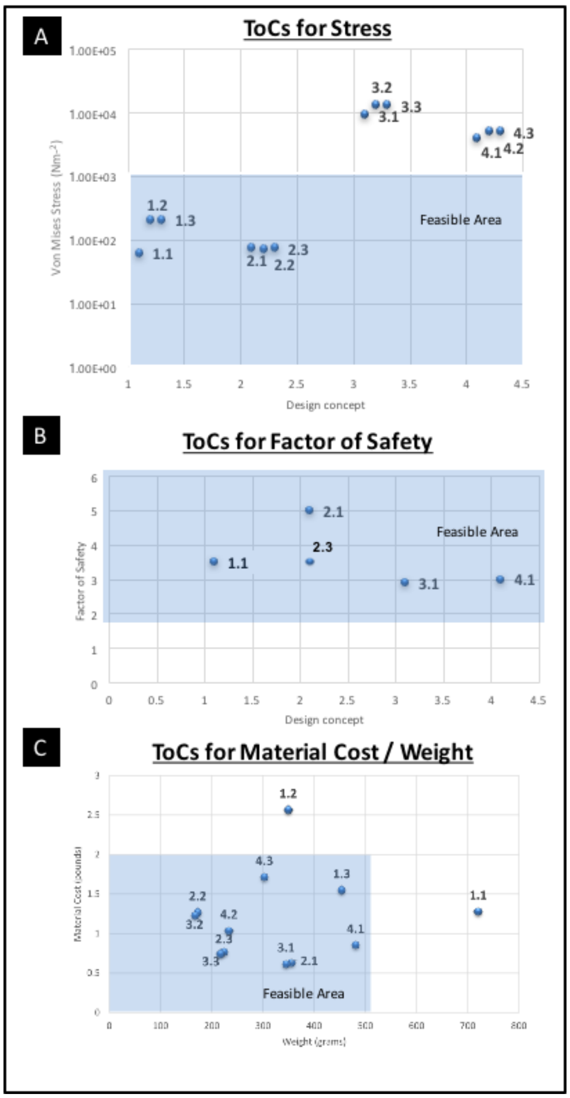

Fig. 8 Example of ToCs for bracket

Phase 4: Converge on System

To obtain the optimal brake pedal box design, alternatives which were not increasing the design performance were discarded and the rest of the possibilities were developed until the optimum design solution was achieved.

The total number of combinations was reduced from 144 to 6. These were then intersected and simulations were performed on these sets (load simulation of assemblies).

4.1 Determine Intersections of Sets

In the activity "Determine intersections of sets", the final brake pedal designs were generated using feasible component set of solutions. From 6 possible combinations, this number was narrowed down by using a lateral test simulation, as shown in Figure 9. From the lateral test simulation result, again the ToCs were used to narrow down the solutions as depicted in Figure 10. With the same method used in activity 3.3 "Explore Sub-Systems Sets: Prototype and Test", the focus was to identify the solutions that could satisfy each of the ToCs values in the feasible area. A combination that does not satisfy any of the ToCs values will be discarded from consideration. As a result, the design solutions were reduced from 6 to 3 which is; 1) B2.3+PA2.1, 2) B2.3+PA2.3, and 3) B2.3+PA3.1.

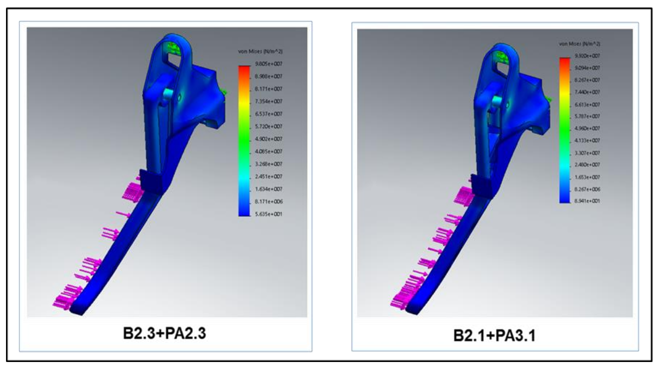

Fig. 9 Example of lateral test simulation

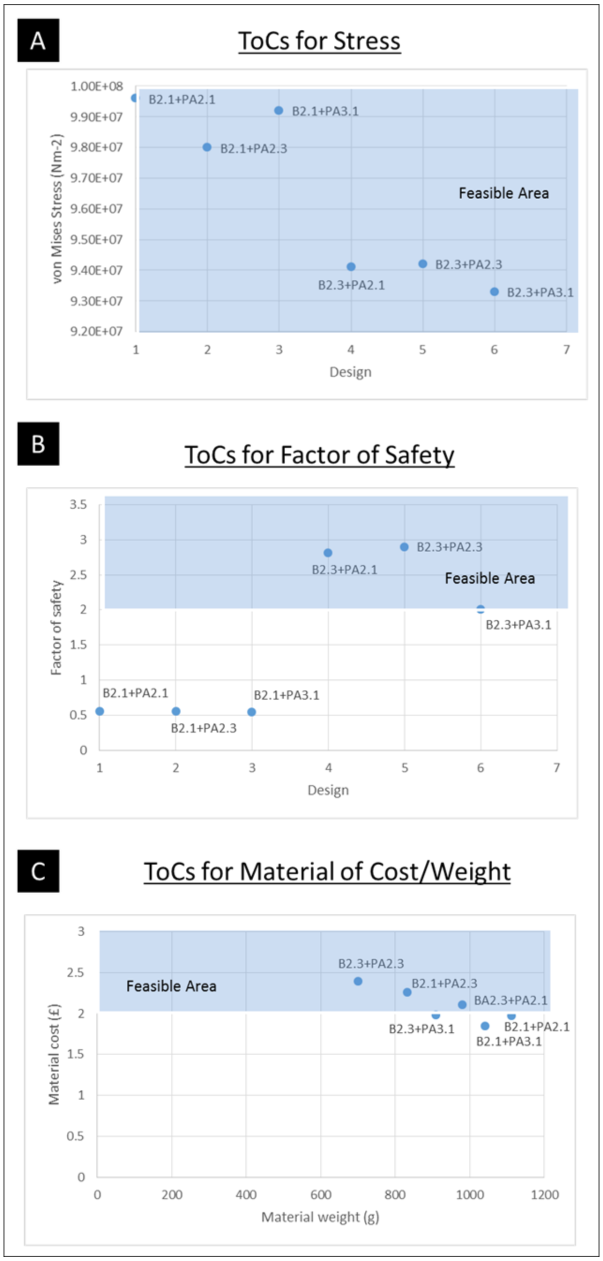

Fig. 10 ToCs for brake pedal box

4.2 Converge on Final System

In activity 4.2 "Converge on final system", a narrowing process was performed based on the loads of importance from the KVAs. To achieve the final optimal solution for the brake pedal box, a Pugh Matrix [21] was used to compare the characteristics and degree of targets met of the last 3 design solutions from the intersection of sets with the weightings of the key value attributes. The performance scale was from 1-4, with 4 being the best in terms of targets met and 1 being the worst in terms of targets met as illustrated in Figure 11-A. The ratings of each design were then multiplied by the loads of the importance of the KVAs in Figure 11-B. The design solution with the highest total weighting was then selected as an optimal design solution. For instance, design "B2.3 + PA2.3" had a rating of 4 for safety, 3 for reliability and 2 for stiffness. These total weighting was then evaluated as follows:

(39% x 4) + (35% x 3) + (26% x 2)= 3.13

The weightings calculations for the other 3 concepts was done the same way as above. As a result, the optimal solution of the brake pedal is the B2.3+PA2.3 system which gives the highest score of 3.13 as depicted in Figure 11-B. Thus, this solution will be chosen to be the final optimal solution which then will be released to the final specification in the detailed design. The detailed design of the final optimal solution shown in Figure 12.

A

	Scale
4	The Best
3	Good
2	Moderate
1	The worst

B

Key Value Attributes	Loads of importance	B2.3+PA2.1	B2.3+PA2.3	B2.3+PA3.1
Safety	39%	3	4	1
Reliability	35%	2	3	1
Stiffness	26%	1	2	4
Weighted Total		2.13	3.13	1.78

Fig. 11 Pugh Matrix for brake pedal box

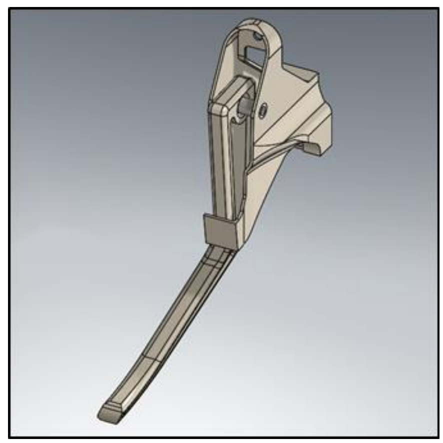

Fig. 12 Final Optimal Solution for brake pedal box

V. The Benefits of the SBCE in Brake Pedal Case Study

The SBCE case study shows the "how to" of implementing a LeanPD mind-set approach. It reconsiders the design and development processes in a way that enhances innovation, reduces rework and improves the success probabilities [22]. A detailed list of the measurable benefits that can be extracted from implementing the SBCE case study are shown in Table 5. This section explains the detail processes of phase 4 in the proposed SBCE framework, as illustrated in Figure 13.

Category	Improvements	Improvement Percentage
1. Product Innovation	1.1. Large increase in number of designs generated.	Product innovation increased from 1 to 144 possible design configurations
2. Product Performance	2.1. Bracket Stiffness	Improved by 92%
	2.2. Pedal Arm Stiffness	Improved by 68%
	2.3. Weight	Weight reduction by 85%
	2.4. Material Cost	Cost of materials was reduced by 45%
	2.5 Reliability (Factor of Safety	Improved by 45%
3. Risk	3.1. Improved probability of project success	99.9% success rate; average of 122 successful designs
	3.2. Improved risk of failure	Risk of failure reduces from 25% to 0.0002%

Table 5 The SBCE benefits in the brake pedal box case study

The brake pedal case study shows the detailed application of the SBCE process model in the real scenario. This case study has benefitted the company by enhancing its current product development process as it provides an opportunity to explore alternative designs from different angles like the product performance, product innovation, and cost. The SBCE approach guided the development of a brake pedal box with the right design and engineering activities as well as the associated tools and method to enable the application of the different activities. In addition, the SBCE approach provided a suitable knowledge environment to support decision making throughout the development process. The benefits achieved in Table 5 shows the capability of the SBCE in providing the right solutions and at the first time.

There are several tangible benefits which could be seen as an evidence in addressing the challenges in Table 1. Typically, a business case is built on the return on investment, However, during the early stage of SBCE introduction, the business case is based on the potential tangible benefits in a few key areas which is; 1) Improved product innovation, 2) Improved product performance, 3) Minimised impact of material cost, and 4) Maximized probability of project success.

The innovation and knowledge creation level has increased: 144 system design configurations were identified through the application of the SBCE process model in the case study. This could give an opportunity for the designers and engineers in JLR to explore the possible designs within the design space without any difficulties from the current product development practices. The 144 design solutions have been generated based on creativity which corresponds to the key value attributes; safety, reliability, and stiffness.

Secondly, product performance has improved through an implementation of the SBCE. Improvements were achieved in four areas which are stiffness, weight, material cost, and, factor of safety (reliability). These improvements have been gained through an analysis using Solidwork software for the bracket and pedal arm. The result was based on the comparison of the component boundary data as shown in Table 4. The analysis of the stiffness originated from the equation of von Mises Stress which connected using distortion energy failure theory [23]. These could be analysed quickly through von Mises stress analysis simulation in Solidwork software. From the analysis, the von Mises stress was carried out at component level, which is the bracket and pedal arm. The comparison of the result is between the component target and final solution. The von Mises stress for the bracket and pedal arm was improved by 92% and 68% respectively. The weight of the brake pedal box was reduced by 85%. As the weight reduced, the material cost also reduced by 45%. This is achieved through an alternative material selection of magnesium alloy instead of steel in the original design. In addition, the factor of safety of the brake pedal box has improved by 45% which increase its reliability and performance.

The probability of having a successful project also was increased by implementing the SBCE in the product development. The test is to show how SBCE was able to eliminate the rework activities in product development by having the highest rate of successful designs and least percentage of failure risk. According to [21], 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 144 possible solutions obtained from using the SBCE approach and one solution in traditional point-based design approach. The possible solutions were taken from the activity 3.2 “Create Sub-System Sets” as each of the subsystems at this stage has a potential to integrate with 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 99.9%, with an average of 122 successful designs compared to 32% with the average only 0.85 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 failed design also was reduced from 25 % to 0.0002 % 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.

VI. Result and Conclusions.

The data from literature review, performance measurement, face-to-face interview, and case study mentioned in previous sections has provided a foundation in developing a SBCE-Business Case Framework (SBCE-BC) and its following implementation as shown in Figure 13.

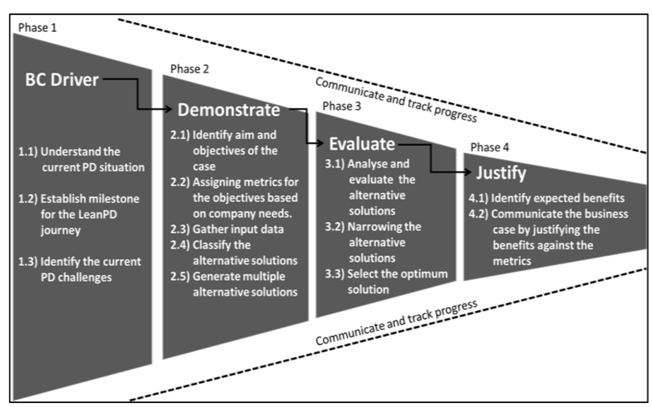

Fig. 13 The SBCE-BC Framework

The framework is established in a four-phase approach where each of the phases consist of a series of activities which aligns with the details of LeanPD through SBCE approach, explained in section 5, section 6, and section 7. Following of the detailed step-by-step explanation in section 5,6, and 7, the SBCE-BC framework phase are categorised into; Phase 1: BC Driver, Phase 2: Demonstrate, Phase 3: Evaluate, and Phase 4: Justify. Each of the phases has its own focus in order to achieve the desired aim. The aim of the framework is to provide a guideline in developing a business case for the introduction and applications of the Set-Based Concurrent Engineering (SBCE). The following paragraph explains the phase of the SBCE-BC Framework.

Phase 1: BC Driver

Phase 1 provides a basic structure for formulating business case in the SBCE. The steps involved in Figure 13 are supported by well-established tool and methods which are the LeanPD SMART Assessment Tool and a face-to-face interview using a semi-structured questionnaire. Phase 1 is considered as a foundation to support the entire framework, particularly in formulating a business case. The first phase consists of several steps to follow which are 1.1) Understand the current PD situation, 1.2) Establish milestone of the LeanPD journey, and 1.3) Identify the current PD challenges. The steps involved in Phase 1 is supported by the method shown in Table 6. The purpose of Phase 1 "BC Driver" is to have an access to promoting a LeanPD environment by understanding the current PD practices and identify the current PD challenges facing in the company. The outcome of Phase 1 is to identify the gaps and PD challenges as well as to have a measurable indicator to monitor the progress of the LeanPD journey.

Steps	Description	Method
1.1	Understand the current PD situation	1) The LeanPD Performance measurement 2) Face-to-Face Interview via Semi-structured Questionnaire
1.2	Establish milestone of the LeanPD	1) SMART Scale
1.3	Identify the current PD challenges	1) List of Key PD Challenges 2) Brainstorming

Table 6 Description of guideline and method for Phase 1: BC Driver

Phase 2: Demonstrate

Phase 2 demonstrates the application of the SBCE based on the findings in Phase 1. In this phase, pilot project or case study were selected. The choice could be a complex or a less complex project depending on company preferable choice. The purpose of Phase 2 "Demonstrate" is to show the effectiveness of the SBCE application in addressing the challenges listed in Phase 1. The second phase consists of five steps to follow which is 2.1) Identify aim and objectives of the case 2.2) Assigning metrics for the objectives based on company needs, 2.3) Gather input data, 2.4) Generate multiple alternative solutions, and 2.5) Classify the alternative solutions. The step involved in Phase 2 "Demonstrate" supported by the method shown in Table 7. The outcome of Phase 2 is generating and exploring multiple alternative solutions based on the aim of the project.

Steps	Description	Method
2.1	Identify the aim of the project	1) Define customer value 2) Analytical Hierarchy Process Matrix 3) Key Value Attributes (KVA)
2.2	Assigning metrics for the aim based on company needs.	
2.3	Gather input data	1) System target for KVA
2.4	Classify the alternative solutions	1) Decide on Level of Innovation 2) System or sub-system/component boundaries
2.5	Generate multiple alternative solutions	1) Create sub-system/component sets

Table 7 Description of guideline and method Phase 2: Demonstrate

Phase 3: Evaluate

Phase 3 provides a structure for evaluating the multiple alternative solution using the outcome of Phase 1 "BC Driver" and Phase 2 "Demostrate". The evaluation process consists of three different methods such as engineering solution, mathematical solution, and subjective decisions subject to the level of complexity of the project. The purpose of Phase 3 is to analyse and evaluate the alternative solutions in a structured way. The result from the analysis will be used to narrow down the solution as well as to identify the expected tangible and intangible benefits in Phase 4 "Justify". The Phase 3 "Evaluate" consists of three steps to follow which is; 3.1) Analyse and evaluate the alternative solutions, 3.2) Narrowing the alternative solutions, and 3.3) Select the optimum solution. The step involved in Phase 3 "Evaluate" is supported by method shown in Table 8. The outcome of Phase 3 is to reach an optimal solution for the project.

Steps	Description	Method
3.1	Analyse and evaluate the alternative solutions	1) Engineering drawing and simulation 2) Trade-off Curves (ToCs) analysis
3.2	Narrowing the alternative solutions	
3.3	Select the optimum solution	1) PUGH Matrix of KVA

Table 8 Description of guideline and method for Phase 3: Evaluate

Phase 4: Justify

Phase 4 outlined the structure to justify the effectiveness of the SBCE by justifying the tangible and intangible benefits against the PD challenges in Phase 1 and metrics in Phase 2. The process of identifying the tangible and intangible benefits is established in a few key areas of improvement for instance product innovation, performance, cost and risk. The key areas of improvement are summarised in the structured table as a communication tool which specify the category of improvement, a description of the improvement, and improvement percentage. The result of Phase 3 will be an input data in identifying both benefits. The Phase 4 "Justify" consists of two steps to follow which are: 4.1) Identify expected benefits, and 4.2) Communicate the business case by justifying the benefits against the metrics. The step involved in Phase 3 "Evaluate" is supported by the method shown in Table 9. The outcome of Phase 4 is to justify the effectiveness and the ability of the SBCE addresses the PD challenges by providing the tangible and intangible benefits which could help the buy-in process to implement the SBCE in the company through a well-structured business case.

Steps	Description	Method
4.1	Identify expected benefits	1) Engineering calculation method 2) Probability test 3) Cost calculation method
4.2	Communicate the business case by justifying the benefits against the metrics	

Table 9 Description of guideline and method for Phase 4: Justify

As summarised, the research shows the purpose of SBCE-BC framework in providing a clear guideline to justify the benefits of the SBCE application. The SBCE-BC framework was found to be a structured guideline as it facilitates the process of identifying the potential benefits of the SBCE. The LeanPD assessment, face-to-face interview and brake pedal case study are used to verify the proposed framework. The result show that the proposed SBCE-BC Framework is quite promising.

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References

[1] Curwen, L. G., Park, J. and Sarkar, A. K. (2013), "Challenges and Solutions of Sustainable Apparel Product Development: A Case Study of Eileen Fisher", Clothing and Textiles Research Journal, vol. 31, no. 1, pp. 32-47.

[2] Cooper, L. P. (2003). A research agenda to reduce risk in new product development through knowledge management: a practitioner perspective. Journal of Engineering and Technology Management, 20(1), 117-140.

[3] Khan, M. S., Al-Ashaab, A., Shehab, E., Haque, B., Ewers, P., Sorli, M. and Sopelana, A. (2013), "Towards lean product and process development", International Journal of Computer Integrated Manufacturing, vol. 26, no. 12, pp. 1105-1116.

[4] Al-Ashaab A, Golob M, Aliende Urrutia U, Gourdin M, Petritsch C, Summers M and El-Nounu A(2015). Development and application of lean product development performance measurement tool. International Journal of Computer Integrated Manufacturing, 2015. DOI 10.1080/0951192X.2015.1066858

[5] Sobek, D. K., Ward, A. C. and Liker, J. K. (1999), "Toyota's principles of set-based concurrent engineering", Sloan management review, vol. 40, no. 2, pp. 67-84.

[6] Ward, A., Liker, J. K., Cristiano, J. J. and Sobek II, D. K. (1995), "The second Toyota paradox: How delaying decisions can make better cars faster", Sloan management review.

[7] Raudberget, D. (2010), "Practical applications of set-based concurrent engineering in industry", Strojniški vestnik-Journal of Mechanical Engineering, vol. 56, no. 11, pp. 685-695.

[8] Khan, M.S., (2012), The construction of a model for Lean Product Development (PhD thesis), Cranfield University, Cranfield University.

[9] Morgan, J. and Liker, J. (eds.) (2006), The Toyota Product Development System, Integrating People, Process, and Technology, 1st ed, Productivity Press, New York, USA.

[10] Khan, M., A. Al-Ashaab, A. Doultsinou, E. Shehab, P. Ewers, and R. Sulowski. 2011. "Set-Based Concurrent Engineering process within the LeanPPD Process." Proceedings of the 18th ISPE International Conference on Concurrent Engineering, Boston, MA, July 4–8, 2011, pp 433–430.

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

[12] Press, H.B., 2011. Developing a Business Case. Expert Solutions to Everyday Challenges. Boston: Harvard Business School Publishing.

[13] Gambles, I., 2009. Making the business case: Proposals that succeed for projects that work. Gower Publishing, Ltd..

[14] Gliedman, C. e. a., Key Elements In An IT Business Case, available at: http://faculty.uml.edu/dstephenson/technology_class/forrester_reports/Forrester_IT_Biz_Case.pdf

[15] Putten, B. and Schief, M. (2012), "The Relationship Between Dynamic Business Models and Business Cases", Electronic Journal of Information Systems Evaluation, vol. 15, no. 1, pp. 138-147.

[16] Ward, J, Daniel, E., Peppard J. (2008), "Building better business case for IT investments", MIS Quarterly Executive, vol. 7, no. 1, pp. 1-15.

[17] Robinson, H.S., Carrillo, P.M., Anumba, C.J. and Al-Ghassani, A.M., 2004. Developing a business case for knowledge management: the IMPaKT approach. Construction Management & Economics, 22(7), pp.733-743.

[18] Bhushan N. (2004). Strategic Decision Making: Applying the Analytic Hierarchy Process. Springer, London; New York. ISBN-13: 978-8184893236

[19] Schuh, G., & Drescher, T. (2014). Systematic leverage of technological assets: A case study for automated tissue engineering. Journal of Engineering and Technology Management, 32, 76-96.

[20] Araci, Z.C., Al-Ashaab, A., Lasisz, P.W., Flisiak, J.W., Maulana, M.I.M., Beg, N. and Rehman, A., 2017. Trade-off Curves Applications to Support Set-based Design of a Surface Jet Pump. Procedia CIRP, 60, pp.356-361.

[21] Ward, A. C., & Sobek II, D. K. (2014). Lean product and process development. Lean Enterprise Institute, Inc.; 2 edition. ISBN-13: 978-1934109434

[22] Maulana, M.I.I.B.M., Al-Ashaab, A., Flisiak, J.W., Araci, Z.C., Lasisz, P.W., Shehab, E., Beg, N. and Rehman, A., 2017. The Set-based Concurrent Engineering application: a process of identifying the potential benefits in the Surface Jet Pump case study. Procedia CIRP, 60, pp.350-355.

[23] Segalman, D.J., Fulcher, C.W., Reese, G.M. and Field, R.V., 2000. An efficient method for calculating rms Von Mises stress in a random vibration environment. Journal of Sound and Vibration, 230(2), pp.393-410.