BACHELOR ASSIGNMENT

DEVELOPMENT OF THE LEAN PD EFFICIENCY TOOL

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INDUSTRIAL DESIGN

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Preface

In front of you lies the assignment that marks the end of my bachelor study in Industrial design. During my study a wide variety of subjects were covered during many courses, some more interesting than others. The subject and reasoning behind the course productcomplexiteit (product complexity) particularly appealed to me. It completely corresponded with the reason why I started this study: to become a professional who is able to provide the connection between other professionals of various disciplines in order to let them work together and understand each other. It may be no surprise that, when I started to look for a bachelor assignment, I went directly to the docent off this course: Juan. He provided me with an array of possible assignments from which a chose this one.

In hindsight it would have been easier to perform a more practical bachelor assignment at a company. However I have learned a lot about the subject and myself during the assignment and in the end I am glad that I chose this assignment, since I doubt if I would have developed myself to the same level with a different assignment.

In this preface, I would like to take the opportunity to thank the persons who supported me during my study and completion of my bachelor assignment. First I would like to thank Juan Jauregui Becker for supervising my assignment. His support and enthusiasm as my supervisor always provided new insights for my assignment and completion of the assignment. Secondly I would like to thank my parents, brother and girlfriend for supporting me during my study and completion of my assignment.

Douwe van Leeuwen
Enschede 29 July 2016

Abstract

The University of Twente is working on a EU project focussed on improving the new product development (NPD) efficiency of R&D departments. In order to achieve this training and consultancy materials are developed. This project is performed with a consortium of companies. It is necessary to measure the implementation of several Lean techniques at these companies in order to understand the current state of the implementation and to reveal the areas suitable for improvement. Sequentially it is necessary to understand the NPD challenges of the companies to develop the training. Therefore, a measurement instrument is required. This project is about designing this measurement instrument: the Lean PD efficiency tool.

Chapter 1 is an introduction of the research. The introduction explains shortly what Lean product development (Lean PD) is and that the research on Lean PD primarily has been focused on the effectivity aspect of lean. The introduction reveals why the focus is on efficiency for this project.

Chapter 2 contains a literature study on Lean and the structure behind a design process. The literature study reveals the essence of Lean and the building blocks for Lean PD. The essence of Lean can be summarised with: to achieve more with less resources. Lean PD consists of five core-enablers, three of these building blocks contribute significantly to the efficiency aspect of Lean PD. This are set-based concurrent engineering, focus on creating knowledge, and cadenced flow and pull management. The literature study on the structure behind a design process is performed in order to support an analogy between a design process and a manufacturing process. The study reveals how complex a design process is, but that it can be structured as a linear process by making use of a design processing unit (DPU). A DPU describes a design process with three sets of information and a analysis. The three sets of information are: design parameters, scenario parameters and performance parameters.

Chapter 3 results in the design brief for the Lean PD efficiency tool. In order to achieve this result an analysis of an existing model and the analogy between a design process and a manufacturing process were made. These two steps combined with the boundaries of the Lean PD efficiency tool and the literature study this resulted in design criteria focussed on usability and usefulness.

Chapter 4 covers the development of the Lean PD efficiency tool. In order to develop the tool a starting point was determined. The starting point consist of the three core-enablers of lean which are focused on efficiency and their respective capabilities. Subsequently a scoring method and a method of questioning are developed. The scoring method for the tool is based on the SAUCE measuring scale and the method of questioning focuses on allowing participants to use gradual distinction in their answers. Then an analysis of the starting point is made which reveals the aspects of Lean PD which need to be cover by the questionnaire part of the tool. Based on this analysis statements are drawn which correlate with the three core-enablers.

Chapter 5 focusses on the evaluation of the model. Therefore an evaluation strategy, based on three different levels, is described. These levels are: the way the questionnaire is used, the comparability of the tool with the reality and the applicability of the tool for companies. The first

two levels of evaluation are carried out and give insight in how the tool can be improved. This can be achieved primarily by making the questionnaire of the tool more condensed. The evaluation also shows that the tool is promising and can become an accurate tool after improvements.

Chapter 6 contains the final conclusions. The created Lean PD efficiency tool has it flaws but can become an accurate measuring tool for the efficiency of R&D departments in order to get insight in their efficiency levels and NPD challenges. However before the tool achieve this, it needs to be adjusted and re-evaluated using all three evaluation levels.

Chapter 7 covers the recommendations for further research and development of the tool. The main recommendations is to make the questionnaire part of the tool more condensed. This can be achieved by eliminating statements that are too much alike and by performing an additional literature study towards other product development methods. The total tool can be improved by making it more user friendly for the researcher who uses the tool. This can be done by creating a system that processes the results from the questionnaires automatically.

Samenvatting

De Universiteit Twente werkt aan een EU project dat gefocust is op het verbeteren van new product development (NPD) efficiency van R&D afdelingen. Om dit te bereiken wordt er consultancy en trainingsmateriaal ontwikkeld. Dit project wordt uitgevoerd in samenwerking met een consortium van bedrijven Het meten van de implementatie van verschillende Lean technieken bij deze bedrijven is nodig om de huidige staat van de implementatie van Lean te begrijpen en om de gebieden die geschikt zijn voor verbetering aan het licht te brengen. Daarop volgend is het noodzakelijk om de NPD uitdagingen van deze bedrijven te begrijpen zodat de training kan worden ontwikkeld. Hiervoor is een meetinstrument nodig. Dit project gaat over het ontwerpen van dit meet instrument: the Lean PD efficiency tool.

Hoofdstuk 1 is de introductie van het onderzoek. De introductie legt kort uit wat Lean product development (Lean PD) is en dat het onderzoek naar Lean PD voornamelijk gefocust was op het effectiviteit aspect van Lean. De introductie legt uit waarom de focus in dit onderzoek ligt op het efficiency aspect van Lean.

Hoofdstuk 2 bevat een literatuur studie naar Lean en naar de structuur van een ontwerp proces. De literatuur studie laat de essentie van Lean zien en onthult de bouwstenen voor Lean PD. De essentie van Lean kan als volgt worden samengevat: meer bereiken met minder middelen. Lean PD is gebaseerd op vijf pilaren, drie hiervan dragen significant bij aan het efficiency aspect van Lean PD. Dit zijn set-based concrurent engineering, focus on creating knowledge, en cadenced flow and pull management. De literatuur studie naar de structuur van een ontwerp proces is gedaan om de analogy tussen een ontwerp proces en een productie proces te onderbouwen. De studie laat zien hoe complex een ontwerp proces is, maar dat het kan worden weergegeven als een lineair proces door gebruik te maken van design processing units (DPU). Een DOU omschrijft een ontwerp proces met drie groepen van informatie en een analyse. Deze informatie groepen zijn: ontwerp parameters, scenario parameters en prestatie parameters.

Hoofdstuk 3 heeft als resultaat het programma van eisen voor de Lean PD efficiency tool. Om dit resultaat te bereiken is er een analyse van een bestaand model en een analogie tussen een ontwerp proces en een productie proces gemaakt. Deze twee stappen gecombineerd met de grenzen van de Lean PD efficiency tol en de literatuur studie resulteren in ontwerp criteria gefocust op bruikbaarheid en doelmatigheid.

Hoofdstuk 4 behandelt de ontwikkeling van de Lean PD efficnecy tool. Om de tool te kunnen ontwikkelen is er een start punt vast gesteld. Het start punt bestaat uit de drie pilaren van lean die zijn gefocust op de efficiency en de bijbehorende aspecten. Vervolgens is er een beoordelingsmethode en een wijze van vraagstelling vast gesteld. De beoordelingsmethode is gebaseerd op de SAUCE schaalverdeling en de wijze van vraagstelling concentreert zich op het mogelijk maken dat de deelnemers gebruik kunnen maken van graduale onderscheiding in hun antwoorden. Daarna is een analyse van het start punt gemaakt waarin de aspecten die moeten worden behandeld in de vragenlijst naar voren komen. Gebaseerd op deze analyse zijn stellingen opgesteld die samenhangen met de drie pilaren.

Hoofdstuk 5 is gericht op de evaluatie van het model. Hiervoor is een evaluatie strategie op gesteld, welke is gebaseerd op drie verschillende niveaus. Deze niveaus zijn: de manier hoe de vragenlijst wordt gebruikt, de vergelijkbaarheid van de tool met de werkelijkheid en de toepasbaarheid van de tool voor bedrijven. De eerste twee niveaus van de evaluatie zijn uitgevoerd en geven inzicht in hoe de tool kan worden verbeterd. Dit kan voornamelijk worden bereikt door de vragenlijst in te korten. De evaluatie laat ook zien dat de tool veelbelovend is en dat als de tool wordt verbeterd een accuraat meetinstrument kan zijn.

Hoofdstuk 6 bevat de conclusies. De ontwikkelde Lean PD efficiency tool heeft zijn beperkingen maar kan een accuraat meetinstrument worden voor de efficiency van R&D afdelingen om inzicht te krijgen in de efficiency niveaus en de NPD uitdagingen. Echter voordat de tool dit kan bereiken moet de tool worden aangepast en opnieuw geëvalueerd worden met behulp van alle drie de evaluatie niveaus.

Hoofdstuk 7 behandelt de aanbevelingen voor verder onderzoek en de ontwikkeling van de tool. De belangrijkste aanbeveling is om de vragenlijst van de tool compacter te maken. Dit kan worden bereikt door het schrappen van stellingen die te veel op elkaar lijken en een additionele literatuur studie naar andere product ontwikkelingsmethodes. De tool in zijn geheel kan worden verbeterd door de tool meer gebruiksvriendelijk te maken voor de onderzoeker die de tool gebruikt. Dit kan worden gedaan door een systeem te ontwikkelen dat de resultaten van de vragenlijsten automatisch verwerkt.

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Chapter 1 – Introduction

This chapter introduces Lean product development (Lean PD) and explains why this study is performed. This includes a problem statement and the approach method towards the solution for this problem.

1.1 Problem statement

There are many new product development methods and approaches. One of these is the on the Toyota production system based method Lean product development (Lean PD). While Lean is a method that is been in use for more than 25 years there are still aspects that can be discovered, especially in the field of Lean PD. Most of the research done on Lean PD focusses on the increased effectivity resulting from this approach. Besides effectivity Lean also focusses on efficiency. Efficiency for product development can be described as the degree to which the time and resources required to launch a product are minimized (Stern & Whittemore, 1998).

Besides that almost all research on Lean PD is focused on the effectivity aspect, most companies are also primarily focused on the effectivity. However there is an increasing interest in the efficiency part of Lean PD as companies realise that there is much to gain on this aspect. The University of Twente is working on a EU project focussed on improving the new product development (NPD) efficiency of R&D departments. In order to achieve this training and consultancy materials are developed. This project is performed with a consortium of companies. It is necessary to measure the implementation of several Lean techniques at these companies in order to understand the current state of the implementation and to reveal the areas suitable for improvement. Sequentially it is necessary to understand the NPD challenges of the companies to develop the training. Therefore, a measurement instrument is required. This project is about designing this measurement instrument: the Lean PD efficiency tool.

1.2 Approach method

This study approaches the development of the measurement tool as if it were a product that needed to be designed. Therefore a literature study on Lean PD (chapter 2) is performed. The literature study focusses on the different aspects of Lean PD (chapter 2.1) and the structure of design processes (chapter 2.2). The next phase that is performed is the development of the Lean PD efficiency tool. This starts with determining the requirements for the tool (chapter 3). This is done by making an analysis of an existing Lean maturity model (chapter 3.1), defining the boundaries of the Lean PD efficiency tool (chapter 3.2) and by making an analogy between a manufacturing process and design process (chapter 3.3). These steps together result in a design brief (chapter 3.4). When the requirements for the tool are determined the real development of the tool can begin (chapter 4). Therefore a starting point needs to be determined (chapter 4.1). Subsequently a method of questioning (chapter 4.2) and a scoring method (chapter 4.3) need to be established. The determination of the starting point results in various aspects that need to be evaluated (chapter 4.4). When this is done the questionnaire of the Lean PD efficiency measurement tool can be drafted (chapter 4.5). After the development of the tool, it needs to be evaluated (chapter 5). Therefore an evaluation strategy is described which is based on three different evaluation levels (chapter 5.1). After the evaluation of the tool the results of the evaluation need to be discussed (chapter 5.2). From the evaluation and the discussion about the evaluation conclusions are drawn (chapter 5.3). Finally conclusions about the total study can be drawn (chapter 6) and recommendations can be made (chapter 7).

Figure 1 shows an overview of the approach method.

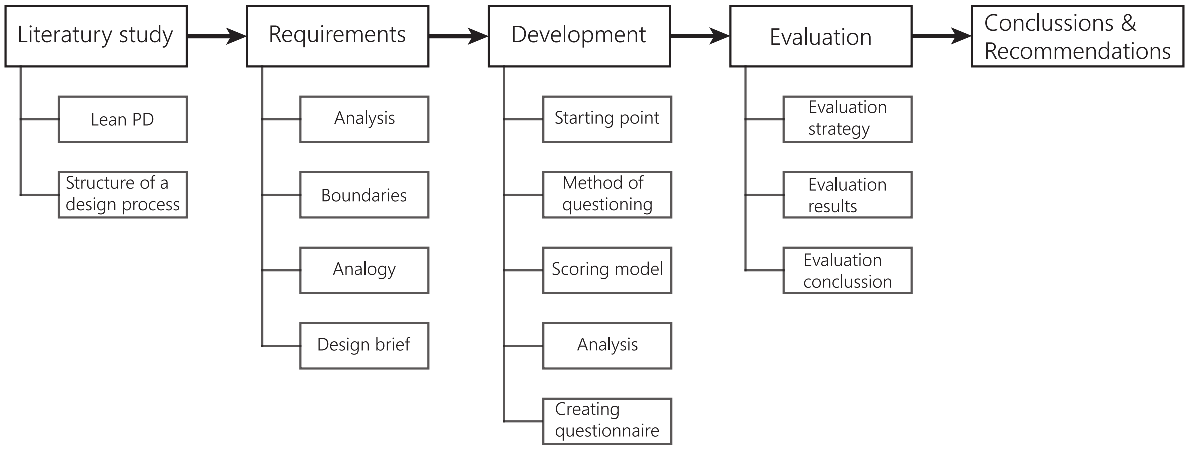

Figure 1. Overview of the approach method

Chapter 2 – Literature

The intention of this study is to develop a measurement tool which gives insight in the level of Lean PD efficiency of development/engineering departments. To understand the concepts of Lean and which of them are suitable for Lean PD and are applicable to the efficiency aspect of Lean PD a literature study is performed. The literature study starts with the basics of Lean and continues into Lean product development.

To be able to achieve the analogy between a manufacturing process and a design process a limited literature study towards Design Processing Unit's (DPU) is made. The goal of the analogy is to provide insight in how the structure of a design process could become more linear. This is necessary because design processes are rather complex and a more linear process shows the influence of the aspects of a design process in relation to each other better than a complex process.

2.1 Lean product development

Lean focusses on creating value, eliminating waste and continuous improvement. The philosophy behind Lean stems from the Toyota production system (Pessôa & Trabasso, 2014). The Lean philosophy strives to enable business to achieve more with less resources while still maintaining and achieving their goals. Lean has particularly been implemented in manufacturing and business processes however the area of product development is also suitable for Lean. Lean can be used to transform new product development from a traditional approach with a fixed sequence of steps towards a dynamic and flexible process (Eshuis, 2015).
Lean product development (Lean PD) can be described in many ways. This is due to the different applications which resulted in different perspectives on Lean PD. Khan et al. (2013) describe these perspectives and Eshuis (2015) summarizes them in three categories:

1. Those who rebranded concurrent engineering as Lean PD.
2. Those who envision Lean as in Lean manufacturing and adapt its elements to their product development.
3. Those that identified Lean PD as the Toyota Product Development System, with its principles and mechanics.

As the rebranding suggest the first perspective is not anything else than performing tasks concurrently. This perspective does not strive to eliminate waste or to add value and is therefore not a suitable perspective. According to Khan et al. (2013) the second perspective leads to a number of inconsistencies, for instance the output of a development process is not a physical product received by a customer or poor quality is not recognised as waste. Only the perspective that is based on the cricital elements of the Toyota development system is a good base for Lean PD (Khan et al., 2013).

According to Khan et al. (2013) there are five core enablers for Lean PD which derive from the Toyota PD system. These five elements combined form the conceptual Lean product and process development (Lean PPD) model depicted in figure 2. Eshuis (2015) describes the five core enablers:

1. Set-based concurrent engineering (SBCE): Simultaneously explore sets of solutions for every (sub)-system, by adding more details and requirements during the development process and progressively eliminate weak solutions by continuously analysing and testing, until the process converges on a solution.
2. Entrepreneur system designer: A multi-disciplined skilled project leader who is responsible for creating profitable products.
3. Focus on creating knowledge: Creating knowledge and hardware through rapid learning cycles to develop products that customers actually want.
4. Teams of responsible experts: a team containing experts on all the disciplines in product development, they have clear individual responsibilities but are responsible as a whole for the success of the project.
5. Cadenced flow and pull management: eliminate wasteful management structures and reports by making sure that knowledge is available at the right time, at the right place, at the right person.

While every element contributes to the Lean PD efficiency level, the contributions are not of the same level. To explore which elements are the main contributors to the Lean PD efficiency level, each element is studied.

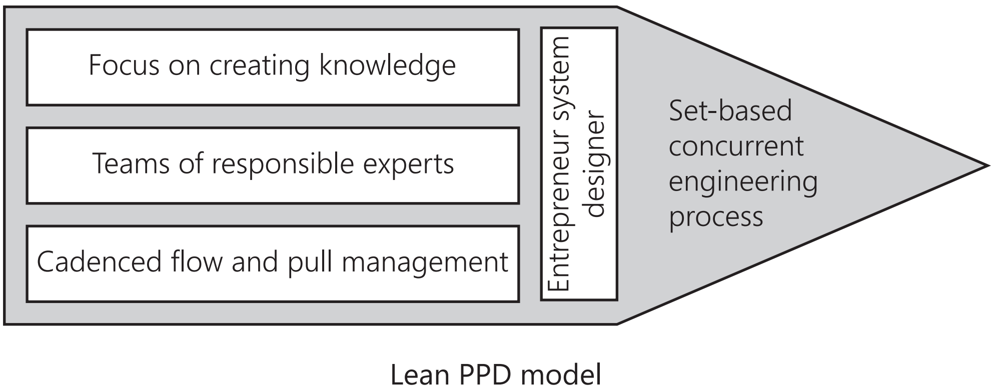

Figure 2. Lean PPD (Khan et al., 2013)

Set-based concurrent engineering

Set-based concurrent engineering (SBCE) can be defined as a process where sets of solutions for different sub-assemblies and components are developed in parallel (Al-Ashaab et al. 2015). SBCE focusses on selecting the best solution for every (sub)-system. This is done by converging from a set of solutions towards the best possible solution through simulations, prototyping and testing. By doing so the lesser solutions will be exposed and will be phased out of the selecting process. The SBCE process is divided in five phases as described by Khan et al. (2013). These phases are: Strategic value research and alignment, Map the design space, Create and explore multiple concepts in parallel, integrate by intersection and establish feasibility before commitment.

The first phase, strategic value research and alignment, focusses on establishing the customer value for a project and aligning this with the company value strategy. This is translated into feasible terms for designers/developer/engineers. Next in the second phase, map the design space, the project is broken down into subsystems and essential characteristics for the system are determined. The third phase, create and explore multiple concepts in parallel, focusses on pulling innovative concepts from research and development and creating multiple design alternatives. To ensure innovative concepts the amount of constraints is kept low, however manufacturing is involved to ensure the tolerance based on process capabilities (Eshuis, 2015). The developed concepts for all sub-systems are tested by preforming simulations, testing prototypes and analyses. During this phase weaker alternatives are eliminated, knowledge is increased and knowledge is captured. The information/knowledge acquired during this process is transferred into a trade-off knowledge base which can be used for the design and future projects. This can be done by visualisations, trade-off curves and check-sheets. The fourth phase, integrate by intersection, focusses on finding similarities between sub-systems and enabling combining those sub-systems. This results in several solutions that fit the intersecting sub-systems. In the last phase, establish feasibility before commitment, the solutions are filtered by increasing the level of detail for the design and increasing the amount and level of constrains. This is done until one final solution remains. The selection of solutions and other mayor decisions are postponed as much as possible to ensure that the decisions are not made based on insufficient knowledge.

According to Al Ashaab et al. (2013) SBCE has six advantages compared to conventional approaches. These are:

1. Avoidance of costly reworks in later design stages.
2. Reaching optimum solutions by ensuring that all functions are involved in the design process simultaneously, and all the alternative solutions fall within the intersection of these functions.
3. Efficient communication where the whole set of possible solutions is described and where earlier communications are still valid but become more detailed and precise.
4. Innovation and creativity are enabled by set-based solutions, flexible designs, delayed decisions and gradual convergence.
5. Organisational knowledge and learning is promoted by capturing, sharing and implementing the knowledge produced throughout the entire PD process.
6. Risk of failure is reduced because of the considerable number of generated solutions.

SBCE contributes substantially towards the efficiency resulting from Lean PD. This stems from the avoidance of reworks, the efficient communication resulting from SBCE, the flexible designs, delayed decisions and the capturing and sharing of knowledge.

Entrepreneur system designer

Product development can be a chaotic process. In order to have a project development project succeed there is a great need for a good leader. In Lean PD that role is reserved for the entrepreneur system designer. According to Ward & Sobek Ii (2014) he must inspire and guide his team to great, successful and profitable products. The system designer should be an entrepreneur, a guardian, and responsible for the vision, success and profits of the product and its development. According to Holman et al. (2003) he should manage knowledge and thus provide knowledge to the right persons.

Eshuis (2015) summarizes the three roles that an entrepreneur system designer must have as described by Clark & Wheelwright (1993). These are the multi-disciplined skilled problem solver, the direct market interpreter and the direct engineering manager. The multi-disciplined skilled problem solver is a leader that has skills in all disciplines that are involved during the product development process of the project he is working on. The direct market interpreter is a leader that is able to obtain first-hand information from dealers, marketing and customers. He is able to transform this information in a new, compelling and feasible vision for a product, its features and its manufacturing process. He is also able to communicate this vision. The direct engineering manager is a leader that is directly involved with the engineers assigned to his project. This enables him to inspire, lead and evaluate.

Focus on creating knowledge

In Lean PD focus on creating knowledge is a key-factor. Lean PD stimulates the creation and capturing of knowledge. Lean PD stimulates this because it adds value to a product, as this is done by knowing and understanding the needs of the customer and understanding how those needs can be fulfilled. (Ward & Sobek Ii, 2014). According to Eshuis (2015), Lean PD focusses on three subjects concerning knowledge. These are knowledge capture, knowledge management and knowledge waste.

By capturing knowledge a company is able to reuse the obtained knowledge and to share it through its organisation. However it is important how the knowledge is captured. Besides its form (reports, checklists, drawings, trade-off curves) it is important that the context and process behind the knowledge is captured (Ghaedian & Chen, 2012; Hauschild et al., 2001). If knowledge is not acquired, it cannot be applied in other situations. Therefore, it is important that a company makes use of a standardisation towards the capturing of knowledge. This allows a good knowledge management system where all information is documented the same way. This makes it easier to make sure that the right knowledge is available at the right time and place (Ghaedian & Chen, 2012).

While knowledge can contribute to the development process in a company, it also can become waste. This happens when the acquired knowledge or the process behind the acquiring does not add value to the product. According to Ward & Sobek Ii (2014) there are three types of waste. These are: scatter, hand-off and wishful thinking. Eshuis (2015) describes these types of waste. When the right knowledge is not available at the right time and the right place it is considered scatter waste. When there is separation of knowledge, responsibilities, action and feedback it is hand-off waste. And wishful thinking is operating and making decisions without data to support it.

Knowledge is a concept that is hard to grasp. Especially when it comes to knowledge waste. This is because it might not be clear if presumed knowledge waste is actual waste. It is possible that knowledge that is labelled as waste for a project is vital for other, future projects or for the company as a whole. As stated before knowledge that does not add value is considered waste, however it can be argued that if the acquired knowledge adds value to the company it cannot be considered as waste.

Team of responsible experts

The development of a product is done by a team of experts who are led by an entrepreneur system designer. According to Clark & Wheelwright (1993) a team consists of cross-functional persons who focus on one project. Every core member is specialised in a discipline that is needed for the product development. Usually every discipline is represented once in the core team. Besides of the core members of the team there are members that support the core members and work on multiple projects (Eshuis, 2015).

In comparison with conventional product development, the core members in Lean PD have the power and responsibility to improve the performance of the project by for example changing tasks (Eshuis, 2015). There can be made a distinction between functional responsibilities, which refer to tasks for the core member, and team responsibility, which refer to tasks for the team. Eshuis (2015) summarises the responsibilities found by Clark & Wheelwright (1993). The functional responsibilities are: ensuring functional expertise on the project, representing the functional perspective, ensuring that sub-objectives are met and ensuring that functional issues affecting the team are raised. The team responsibilities are: sharing responsibility for the team, reconstituting task and content, establishing reporting and other organizational relationships, participating in monitoring and improving team performance, sharing responsibility for ensuring effective team processes, examining issues from an executive point of view and understanding, recognizing and responsibly challenging the boundaries of the project and team process.

Cadenced flow and pull management

Cadenced flow and pull management lowers development times by eliminating time waste. According to Eshuis (2015) the main enabler for lowering these development times is Just-in-time (JIT) engineering. JIT focusses on postponing decisions until all vital information is available to make the decision. This leads to better development times in comparison with conventional product development. Conventional product development makes use of fixed decision gates, which can result in wasting time or in an information gap (Holman et al., 2003). According to Kahn et al. (2013) it is important to have the right information available at the right time and at the right place. This information needs to be pulled by an upstream engineering process from a downstream process, rather than be pushed by the downstream process. JIT engineering enables this, the right information will be pulled when it is needed.

The knowledge pull mindset needs to be integrated in the company culture. When this is achieved a new product development project starts with pull factors. Starting from customer needs and demands which spark the first clue that there is a need of new product (Eshuis, 2015). As described by Eshuis (2015) the research department pulls these needs and demands from the customers and the customer demands establish a time to market and the amount of product needed. However the establishing of a deadline and amount of product needed is not a knowledge pull but a knowledge push action. In a perfect world with unlimited resources this would not happen and the whole product development process would consist of only pull actions (figure 3). In reality this leads to upstream process that push information towards downstream processes instead of pulling information from them. This results in marketing pushing information towards production concerning when and how the product needs to enter the market. Sequentially production will push information concerning when the final design needs to ready towards development. Development will pull information about new techniques and ideas from research (figure 4, Eshuis, 2015). To minimize the time waste the described push actions should be the only push actions in the Lean product development process.

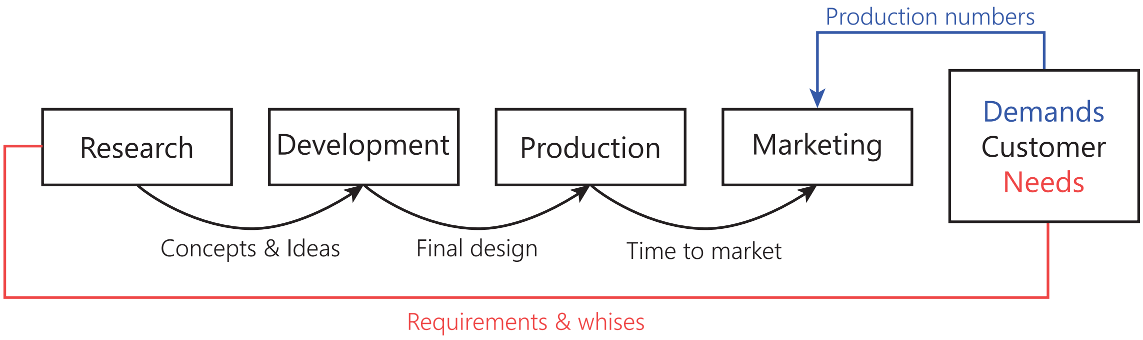

Figure 3. Product development process in a perfect world

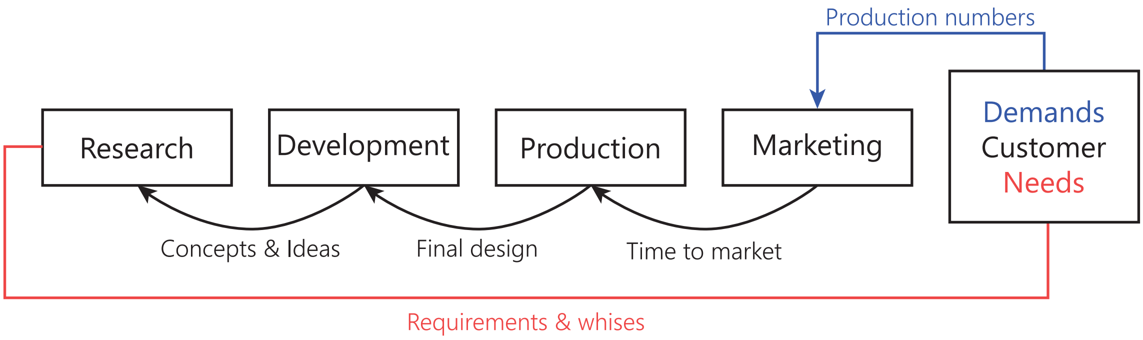

Figure 4. Product development process in reality (Eshuis, 2015)

2.2 Structure of a design process

Design processes are rather complex and opaque. Where manufacturing processes are structured clearly and rather linear, design processes are not that structured and definitely not linear. By comparing figure 5 with figure 6 the difference between the two processes becomes clear. Lean strives to transform complex processes into structured and uncluttered processes.

While design processes are complex, they can be described in a simplified model. This model, figure 7, is based on three possible results from a design process. The first result is a promising design that needs adjustment, the second result is a design that is rejected and the third result is a design that is accepted. These outcomes are supported by knowledge that can be declarative or procedural. Declarative knowledge describes static entities like components, parameters and relations. Procedural knowledge describes dynamic processes like strategies and algorithms (Juaregui-Becker & Wessel, 2012). According to Juaregui-Becker & Wessel (2012) the procedural knowledge cannot be used to describe the essence of a design process. However declarative knowledge can be used by using the three basic types of declarative knowledge present in a design process: embodiment, scenario and performance. These three pieces of declarative knowledge are defined as Design Process Unit (DPU) (Juaregui-Becker & Wessel, 2012).

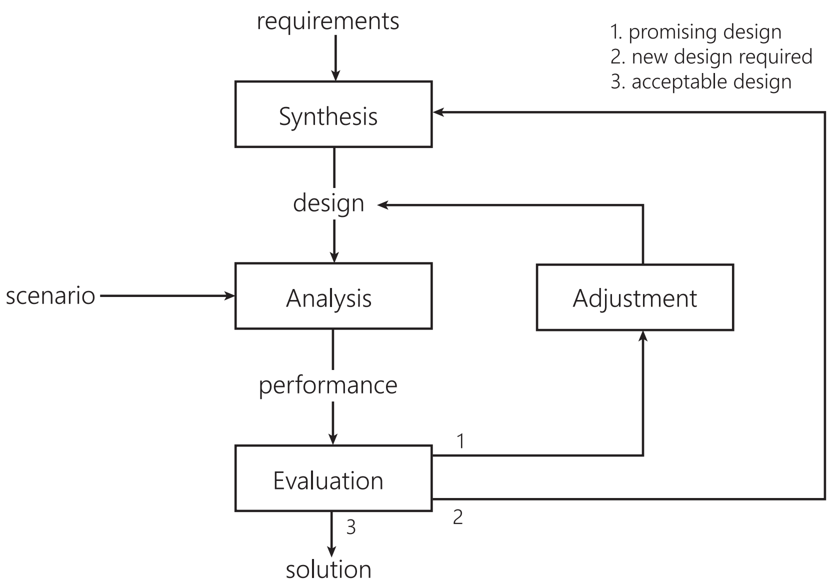

Figure 7. Descriptive model DPU (Jauregui-Becker & Wits, 2012)

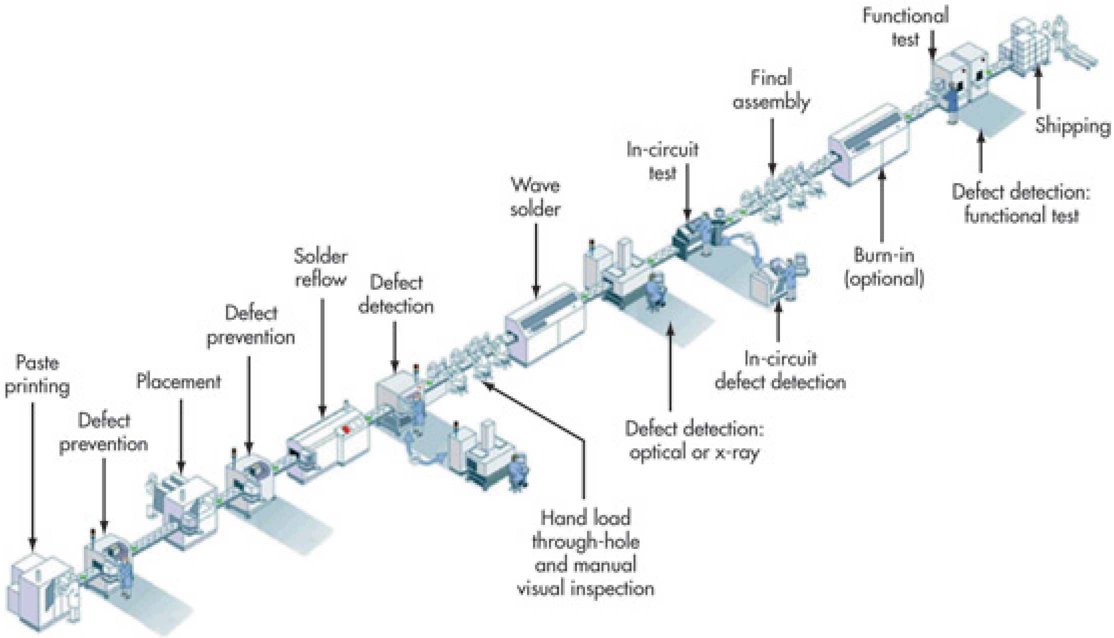

Figure 5. PCB assembly process - A linear process (www.ascos.nl)

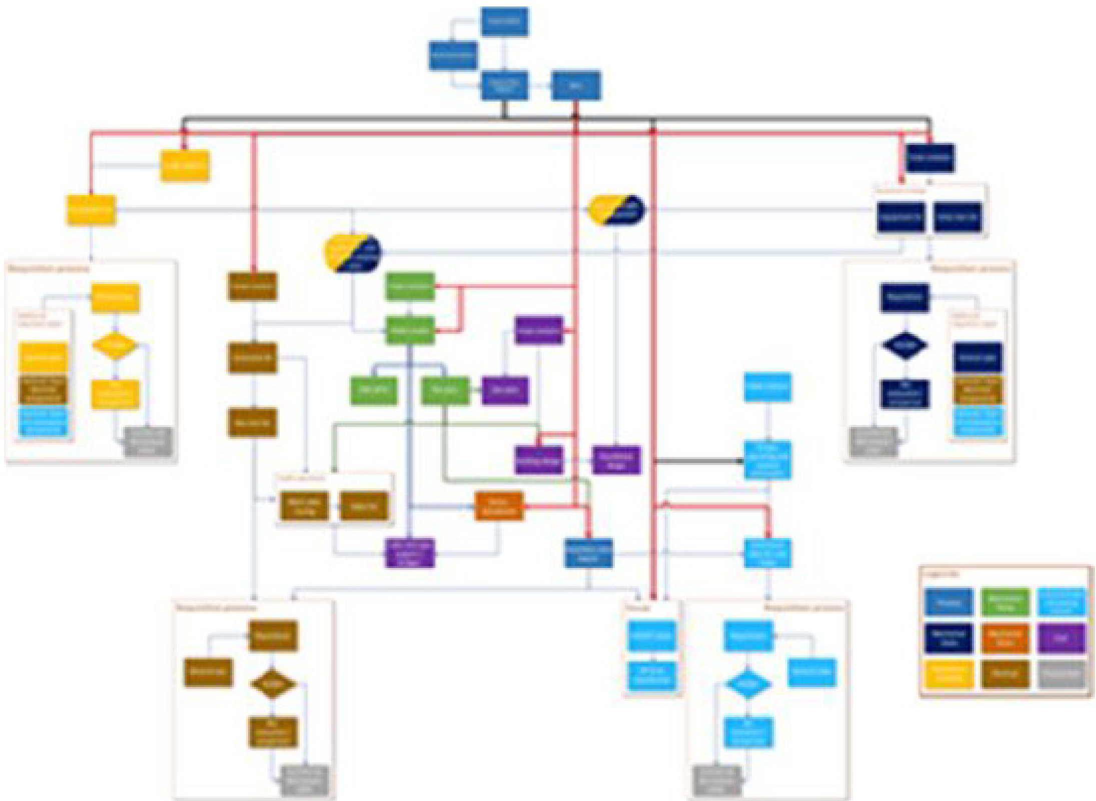

Figure 6. Design process at Thebodin - A complex process

A DPU can be used to give insight in a design of a system. In figure 8 a DPU of a mass-spring system is displayed. There are four key components: the design parameters, the scenario parameters, the performance parameters and the analysis. In a more complex system multiple DPU's can be combined together to create a knowledge structure, in which results from one DPU can function as input for another DPU (figure 9) (Juaregui-Becker & Wessel, 2012). If DPU's can be used to structure the design of a system they could be used to outline a design process in a general description. The design parameters for a design process are the product idea and the existing knowledge. The scenario parameters are the conditions which the design process and the outcome of the design process should meet. These conditions can be: the market conditions, the end user, the time to market, the budget and the design brief. The performance parameters are the parameters that measure the quality. These results can be: the waste generated by the design process, the knowledge acquired during the design process and the final design of the design process. The analysis can be considered as the steps that are necessary to reach the performance parameters using the scenario parameters and design parameters. These steps can be the development/design phases and the design of subsystems (figure 10).

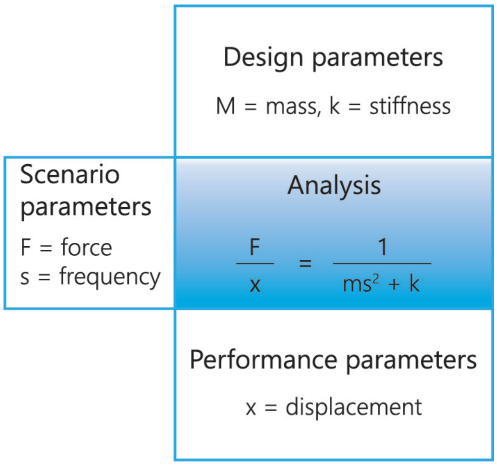

Figure 8. DPU of a mass-spring system (Jauregui-Becker & Wits, 2012)

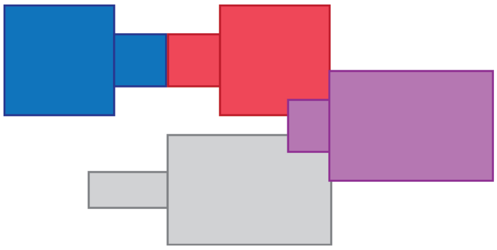

Figure 9. Knowledge structure: each color represents a different DPU (Jauregui-Becker & Wits, 2012)

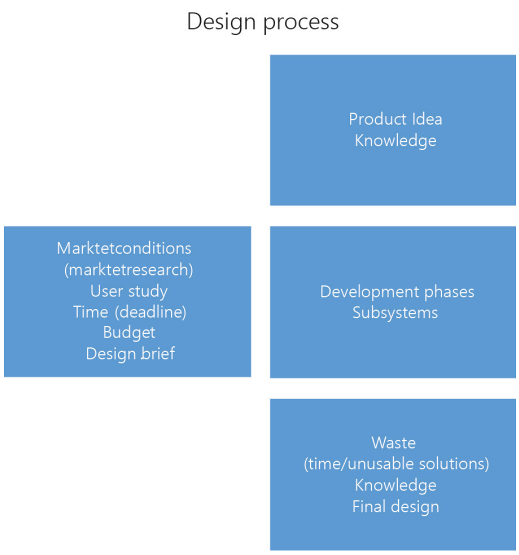

Figure 10. DPU of a design process

Chapter 3 - Requirements

This chapter focusses on the development requirements needed to develop a measurement tool for Lean PD with a focus on efficiency. This is done by making an analysis of the existing Lean maturity model, defining the boundaries of the tool and by making an analogy between a manufacturing process and design process. This is combined with the acquired knowledge from the literature study and results in a design brief for the measurement tool.

3.1 Analysis of the Lean maturity model

There is an existing Lean maturity model developed by Eshuis (2015). This model focusses on creating a total picture of the Lean maturity of the company that uses this model. In order to be able to create this overview the model focuses on all different aspectst of Lean. This results in a very broad and elaborate model. Eshuis (2015) uses 36 capabilities for the total tool, while De Bruin et al. (2005) advice to use not more than 30 capabilities, to minimize the complexity of the model. While the model reaches its goal it is hard to obtain the different maturity levels of separate parts of Lean. Eshuis (2015) uses a modified version of the measuring scale called SAUCE developed by Ahmed Al-Ashaab et al. (2013) to assess each core enabler described in chapter 2.1.

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

While this measuring scale is suitable, the way in which Eshuis (2015) uses the scale is not suitable for a tool focused only on efficiency. The modified version is better suited to more complex models. For the Lean PD efficiency tool the SAUCE scale is sufficient. In order to assess each core enabler he has created multiple choice questions that each contain five answers. These answers correspond with the five levels of the SAUCE scale.

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

Table 1. Example of way of questiong by Eshuis (2015)

While this results in direct feedback about the level of the core enabler it does not leave any room for gradual distinction between the levels. The participants of the Lean maturity model are forced to choose one of the levels, as can be seen in table 1. Besides the forced decision not all questions could be answered on a five point scale. Some questions only had three or four possible answers, this leads towards an more arbitrary analysis of the situation.

However in reality one of the answers does not have to exclude one of the other answers and answers in between levels are possible. For example the answer for level four of the SAUCE scale does not exclude the third answer. Because of this the results of the model can be misleading. While the model concludes that the level according to the SAUCE scale should be four, the reality is that the score should be somewhere between three and four. Therefore it is better to dismantle the questions and use each answer as a separate question. The results from the questions based on the answer combined could provide a more accurate SAUCE level.

3.2 Defining boundaries

In order to be able to develop and design a measurement tool that is adequate for its task some areas need to be explored. First of all, the end user of the tool needs to be determined. When it is clear who is going to use the tool, the environment in which they are going to use the tool needs to be established. Finally the purpose of the measurement tool needs to be determined. This purpose should give an answer to why the end user is using the tool and what he wants to accomplish by doing so.

Target audience

The measurement tool is intended to be used by anyone who wants to measure Lean PD at a company which meets the prescribed requirements. The questionnaire, which is used to obtain data for the measurement tool, is intended to be answered by developers/engineers and project-managers. This focus is chosen in order to create a tool that is easy to implement, while still providing insight in differences between layers within the company.

The scope

The measurement tool is intended to focus on companies with a development/engineering department. These departments should work with multidisciplinary teams consisting of at least three different disciplines. The minimum of different disciplines stems from the team of responsible experts core enabler. For such a team multiple disciplines need to be present, otherwise the team is to specialized on one subject. Besides this scope there is no distinction on the type of product that is developed. The focus within the development/engineering departments should be on developing existing concepts towards a final product. The departments should not focus on the innovation process of entirely new products. However it can and may occur that there is overlap between these two areas. These areas tend to be intertwined with each other.

Purpose of the measurement tool

This measurement tool is developed to measure the performance of a development/engineering department in comparison with their efficiency according to the Lean PD philosophy. This will give insight in the correlation between these aspects. At this moment a lot of companies invest in making their development/engineering departments as Lean as possible. However there is no solid evidence proof that the implementation of Lean PD yields positive results. With a measurement tool which focuses on the performance of a development/engineering department and their efficiency according to the Lean PD philosophy a first step can be made to support or reject the investments to make development/engineering departments more Lean.

In order to be able to measure the efficiency according to Lean, the tool should be focused on measuring the aspects of Lean that influence the efficiency the most. According to the previously presented literature review, five Lean enabling aspects were identified, which are going to be the basis for developing the Lean measuring tool.

3.3 Analogy between a manufacturing process and a design process

An analogy between manufacturing and design process has been made to get a better understanding of how the structure of a design process could become more linear. A more linear design process results in a better and easier understanding of the design process. It becomes more clear which aspects of the design process influence other aspects of the design process.
A design process can be treated as the transformation of market opportunities, in combination with knowledge and production technology, into a market ready product. The comparison with manufacturing can be made by equating the market opportunities and the available knowledge to the raw materials for a manufacturing process. Through making this comparison an analogy between a generic manufacturing process and a design process can be made. Different parts of the two types of processes are compared in table 2.

Manufacturing process	Design process
Data input: Technical drawing/recipes	Data input: Concept
Raw materials	Knowledge
Processing the materials	Converting knowledge in to a design
• Processing (several machines)	• Development/engineering phases (drawings, cad, etc.: several individuals)
• Sub-assemblies	• Sub-assemblies (machatronic design, electronic design, etc.)
• Combining	• Combining (doe the sub-assemblies work togehter, do they fit in the total design)
• Quality assesments	• Rework of not suitable solutions
• Waste	• Waste/Time loss
Output: Final product	Output: Design

Table 2. Comparison between a manufacturing process and design process

Both process can also be displayed as a DPU (figure 11). This provides more insight into the further details of the comparison. For example if there are performance indicators that can be transferred from the manufacturing process to the design process and how the design process can become a more structured and uncluttered process. A DPU also provides insight into which aspects of the design process can be influenced by the department. These are the performance parameters and the analysis. However not all possible aspects of manufacturing processes or design process are displayed. This is done because of the large differences between companies.

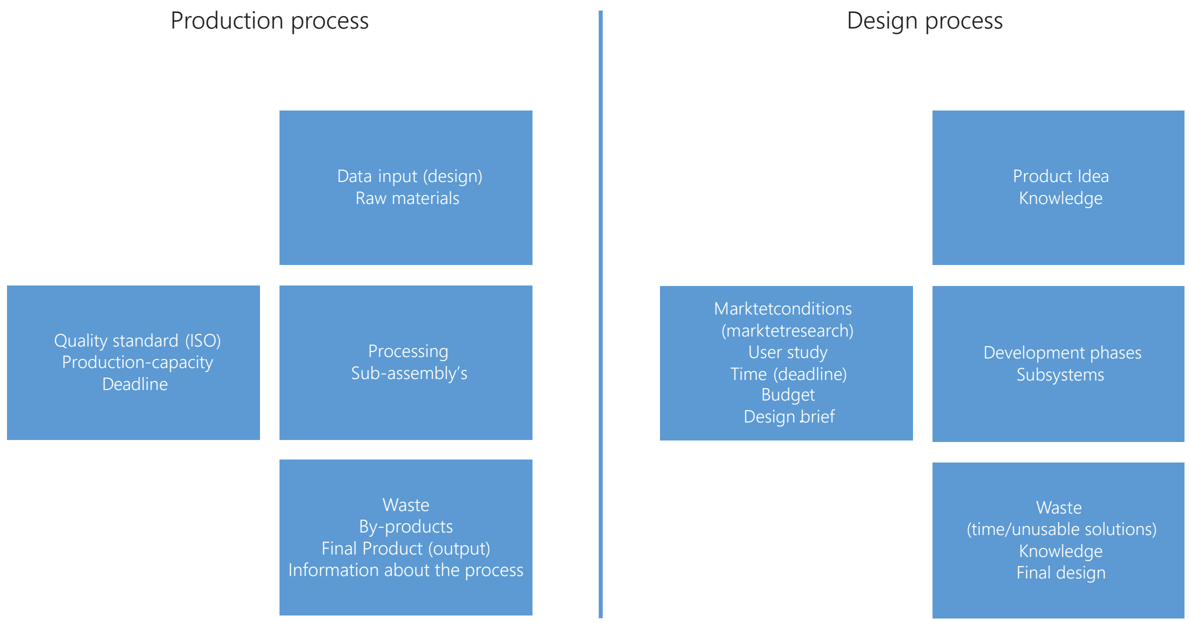

Figure 11. DPU's of a production process and a design process

3.4 Design brief

From the acquired knowledge from the literature study, the analysis from the existing Lean maturity model and the analogy between a manufacturing process and design process combined with the defined boundaries success criteria for the Lean PD efficiency tool can be defined. This is needed to be able to assess if the tool is effective by evaluating the tool in chapter 5. The success criteria can be distinguished by criteria that focus on the usability of the tool and criteria that focus on the usefulness of the tool.

The criteria for the usability of the tool focus on aspects that determine if the tool is practical in real life use. They should determine if the tool is easy to use for the described audience (section 3.2). The criteria for the usability are:

- The terms used in the tool are understandable for the target audience.
- The language used in the tool is understandable for the target audience.
- How the tool needs to be used is clear for the target audience.
- The questionnaire of the tool needs to be completed within 15 minutes.
- The applicability of the tool towards the company of the target audience needs to be clear.
- The applicability of the tool on the correlated subject of Lean needs to be clear to the target audience.

The criteria for the usefulness of the tool focus on the aspects that should be measured by the tool and the applicability of the tool towards the environment described in the scope (section 3.2). The criteria for usefulness are:

- The tool needs to be applicable on development/engineering departments that focus on the realisation of existing concepts.
- The tool takes the difference between efficiency of a development/engineering project and the efficiency of a company as a whole into account.
- The tool uses a maximum of 30 capabilities (De Bruijn et. Al, 2005).
- The tool needs to be suitable for companies that work with multidisciplinary development/engineering departments, consisting of at least three different disciplines.
- The tool measures the extent to which set-based concurrent engineering is applied by a development/engineering department.
- The tool measure the amount of waste (scatter, hand-off and wishful thinking) the development/engineering process entails of a development/engineering department.
- The tool measures the use of flow & knowledge pull in a development/engineering department.
- The tool maps the structure of the development/engineering process in a development/engineering department.
- The tool determines how knowledge is handled by a development/engineering department.

Chapter 4 - Development of the Lean PD efficiency measurement tool

For the development of the Lean PD efficiency measurement tool various steps need to be carried out. First of all a starting point needs to be defined. When the starting point is defined a method of questioning and a scoring method need to be established. Subsequently the aspects provided by the starting point need to be evaluated. When this is done the questionnaire of the Lean PD efficiency measurement tool can be drafted.

4.1 Defining the starting point

The development of the Lean PD efficiency measurement tool is based on the Lean maturity measurement (LMM) tool Eshuis (2015) completed. His work focuses on the whole Lean PD maturity of development/engineering departments while the focus in this study lies on the efficiency aspect of Lean PD. This makes it impractical to just improve the tool developed by Eshuis (2015). However there are aspects that can be reused. In order to do that the LMM tool needs to be divided into the different aspects of Lean PD. Figure 10 shows the LMM with the process areas and capabilities. As explained before the aspects of Lean PD that have the largest influence on the efficiency of a development/engineering department are SBCE, focus on creating knowledge and cadenced flow and knowledge pull. While the entrepreneur system designer and the team of responsible experts both contribute to the efficiency, their contribution is relatively small compared to the other process areas. In order to create a tool that is usable only the three aspect with a large influence are used.

Figure 10 shows also three performance indicators: know your value, know your waste and know your processes. These indicators can be linked correspondently to effectivity, efficiency and flexibility. Eshuis (2015) suggests for future maturity tools to include these performance indicators, in order to create a more usable model. For this model the performance indicators know your waste and know your processes are interesting. Know your value is focused on effectivity and is thus not included by the purpose of this tool.

The value of the indicator know your waste for this tool is almost obvious. This indicator focusses on actions and procedures that cost time, money or resources and do not add value to the product. If there is less waste the company is more likely to be efficient (Eshuis, 2015). The value of the indicator know your process is not directly clear. This tool focusses on the efficiency of development/engineering departments and not on the flexibility of these departments. However aspects that increase the flexibility of the departments can have a strong correlation with the efficiency. The flexibility of product development can be described as the ability to make changes in the product or development process without being too disruptive (Eshuis, 2015). According to this definition a department that is really flexible is able to change aspects in an advanced stage of the product development process without losing to much time, recourses or money. This corresponds with the goals of efficiency.

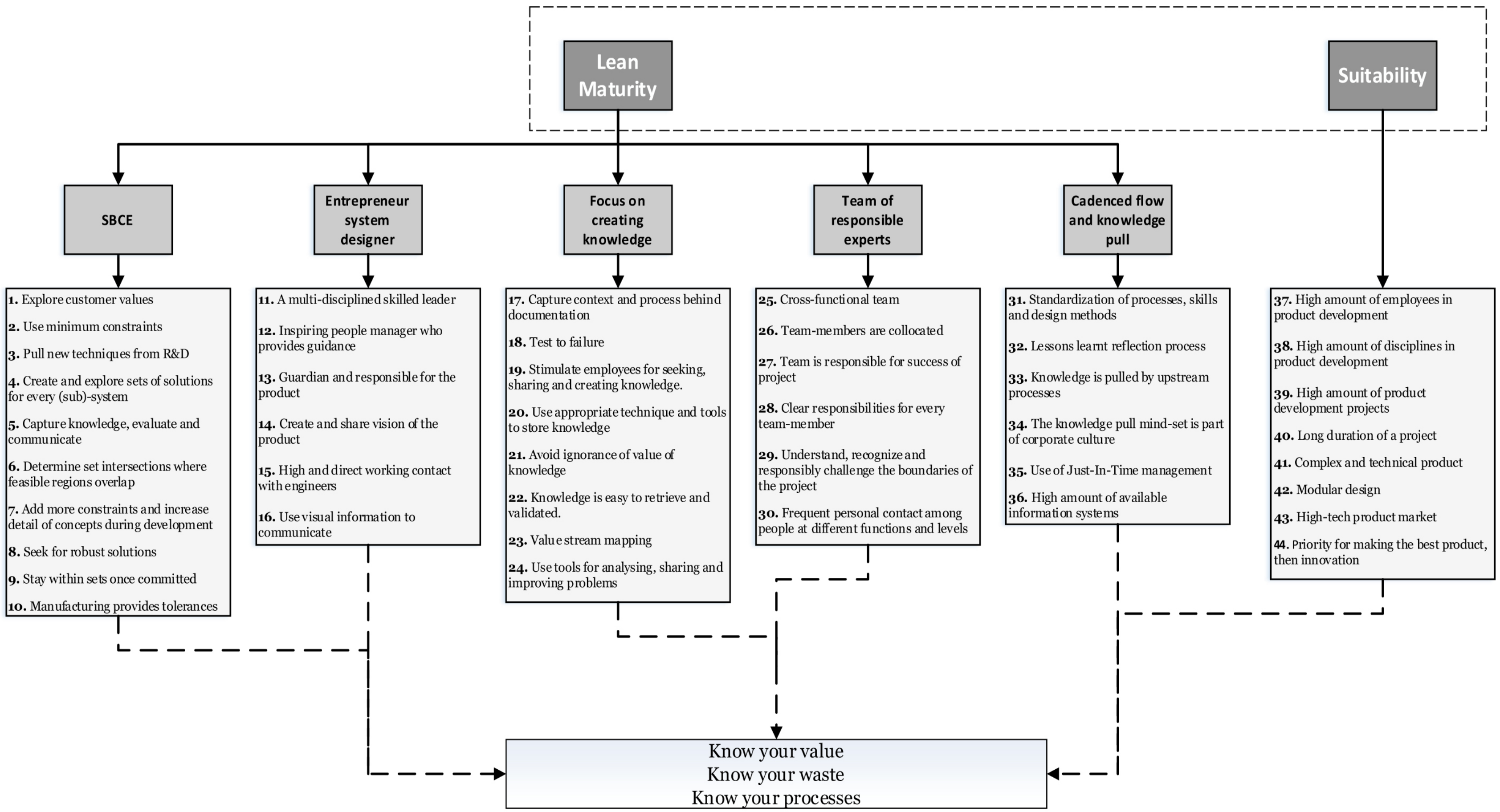

Figure 12. Process areas and capabilities (Eshuis, 2015)

For each process area of Lean PD, which influences the efficiency considerably, and and the performance indicators that correspond with efficiency questions can be drafted. This is done after analysing the process areas with corresponding capabilities and performance indicators displayed in figure 10.

4.2 Method of questioning

The analysis from the Lean maturity model developed by Eshuis (2015) in chapter 3.1 shows that there is room for improvement in how the maturity level is obtained in that model. The participants are forced to differentiate between different options that do not always correspond with the reality. This can lead towards misinterpretation and distorted view of the reality. In order to overcome this problem a different way of questioning is needed. As is stated in the analysis (chapter 3.1) this does not mean that the questions cannot be used anymore. However the way of questioning does need to change, for example by separating each answer possibility and transforming these answers into new questions. The transformed answers can be formulated as statements. This allows the participant to voice their opinion about the statement. As a result the statements that are not true according to the perceived reality of the participant are filtered. The results from the new questions combined can be used to find the SAUCE level of the process areas of Lean PD and the performance indicators described in the previous chapter. These levels combined provide the overall SAUCE level for the Lean PD efficiency.

This new approach needs an method of questioning that allows participants to make a gradual distinction in answering. This can be achieved in various ways. For example by using open questions, allowing participants to score percentages or by using a 5 or 7 points Likert-scale. Each of these options has pros and cons. Open questioning leaves the most room for gradual distinction however this will resolve in a higher effort of both the participant and the interpreter. The participant needs to be able to formulate answers that are applicable to Lean PD and the interpreter needs to translate the answers into usable information. Using scoring percentages also provides room for gradual distinction, however people are accustomed that percentages are related to numbers. Therefore it could result in confusion about the questions. The use of a Likert-scale is one of the best practices in questionnaires. It leaves room for gradual distinction but also guides the participant by providing to opposites to choose from. In combination with the five points SAUCE scale, a five point Likert-scale is a good choice. For example the question from table 1 can be transformed in the multiple questions displayed in table 3. Each point of the Likert-scale corresponds with a level of the SAUCE scale. The highest level of disagreement corresponds with the lowest level of the SAUCE scale and the highest level of agreement corresponds with the highest level of the SAUCE scale.

The statements below, are about the selection of the conceptual design solution that will be developed. Please indicate to what extent you agree or disagree with the statements.					
	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
We only produce one solution for each component or subsystem.	○	○	○	○	○
We only produce one solution but we are aware of the benefits of multiple solutions.	○	○	○	○	○
We identify multiple solutions, and select the solution based on a subjective assessment (experience, previous projects...)	○	○	○	○	○
We identify multiple solutions, and select the solution based on an objective assessment (tests,prototyping...).	○	○	○	○	○
We initiate the design of multiple solutions in all projects, and gradually rule out the weaker solutions based on the knowledge gained from simulation and/or physical testing.	○	○	○	○	○

Table 3. Example of questioning by using a Likert-scale and statements

4.3 Scoring model

In order to translate the outcome of the tool into an understandable Lean PD efficiency level a scoring model is needed. Therefore the added value on the Lean PD efficiency of each process area and the performance indicators need to be set. The process areas SBCE and cadenced flow & knowledge pull and the performance indicator which focusses on waste have the largest influence on the Lean PD efficiency level. Their impact on the score should be larger than the impact of the performance indicator that focusses on the process and the knowledge process area. The impact of a process area or performance indicator can be expressed in a weight for each aspect. In the questionnaire the performance indicators are placed at the most appropriate process area. This means that the weight of these indicators should be reflected in the weight of the process area. The performance indicator which focusses on the process is represented in the questionnaire by the process areas of SBCE and cadenced flow & knowledge pull. The performance indicator that focusses on weight is spread out through the whole questionnaire. This results in a weight of 35% for the process areas of SBCE and cadenced flow & knowledge pull and a weight of 30% for the process area of knowledge, as shown in table 4.

Process Area	Weight
Set-based concurrent engineering	35%
Knowledge focus	30%
Cadenced flow and knowledge pull	35%

Table 4. Process areas and corresponding weights

As describes in the previous chapter each point of the Likert-scale corresponds with a level of the SAUCE scale. The combined results of the questions can be used to calculate the SAUCE level of the corresponding process area or indicator. This can be done by calculating the average, resulting in an average score for the corresponding process area. In cases where a question is suitable for more than one process area, the best suitable process area is selected. The total Lean PD efficiency level based on the SAUCE scale can subsequently be obtained by multiplying the calculated scores for the process areas and indicators with their corresponding weights and adding the results together. Because this will not result in whole numbers in most cases the outcome will be rounded towards the nearest whole number. The obtained number corresponds with a level on the SAUCE scale.

For this scoring model each question needs to be linked to one or more process areas and/or performance indicators.

4.4 Analysing process areas and performance indicators

In order to draft questions for the Lean PD efficiency tool an evaluation of the process areas and performance indicators is necessary. For each process area and performance indicator the areas which the questionnaire should cover are assessed. This is done with the use of the knowledge acquired by the literature study and the analogy between a manufacturing process and a design process. This knowledge is combined with the capabilities provided by Eshuis (2015) shown in figure 12 (chapter 4.1), the literature study. Intersections between different process areas and performance indicators can occur, if so the most appropriate process area or performance indicator is selected. For example the starting point of a development/engineering process is important for SBCE and for the structure of the development/engineering process. For each sub goal minimum objectives are set. Some objectives can merge directly into usable questions in the measurement tool. Other objectives will be achieved by indirect questioning in the measurement tool.

The application of set-based concurrent engineering

SBCE is one of the core enablers for Lean PD efficiency. It eradicates rework, it results in efficient communication and enables the use of flexible designs. To assess the extent to which SBCE is applied within a development/engineering department, the following criteria needs to be measured by the tool:

- What is the starting point of the development/engineering process.
- To what extent the final outcome is defined at the start of the development/engineering process.
- How does the development/engineering department use constraints for a project.
- If the development/engineering department relies on standard design practices or if the best design practices evaluated for each new project.
- If a design phase is conducted once or if they are subject to rework.
- What is the perception concerning a development/engineering project. Is the project a whole or does it consists of several subsystems.
- Whether the final product is delivered on time.

The level of waste

As described before the waste in a development/engineering project is hard to grasp. This is primarily due to the indistinctness to what waste in a development/engineering project is. It is obvious to think of time wasted on solutions that are not applicable. However while those solutions may not be applicable for the current project they may be applicable for later projects. In addition the path towards the right solution may have had detours, this can also be accounted as wasted time. However documenting this waste is challenging because the wasted time may not be perceived as waste.

Since it is impossible to determine if a solution will be used in the future, the measurement tool will focus on the, perceived, waste for a development/engineering project. To assess the amount of waste of a development/engineering project, the following criteria need to be measured by the tool:

- The degree to which knowledge that is acquired during development/engineering projects is not used in the projects.
- The amount of detours before reaching a final design in a development/engineering project.
- The time wasted on detours during a development/engineering project.
- The extent to which there is rework during a development/engineering project.

The application of cadenced flow & knowledge pull

Cadenced flow and pull management lowers development times by eliminating time waste and thus increasing the Lean PD efficiency. This is done by making sure that the right decisions can be made at the right time. To assess the application of cadenced flow & knowledge pull in the development/engineering department, the following criteria need to be measured by the tool:

- If the development/engineering department uses a fixed development/engineering process.
- To what extent JIT-management is used.
- Whether cadenced flow & knowledge pull is applied in the department and if it is a conscious decision or if it is part of the company culture
- How does the department handles the customer response time
- If the schedule for the development/engineering process is fixed or variable.
- How the schedule is established.

The design process

Each company is different and each development/engineering department is different. This makes it challenging to develop a tool that is applicable to each company. However there are parts of the structure of development/engineering processes that are generic. To assess this the following criteria need to be measured by the tool:

- If there is a fixed development/engineering process.
- To what extent the development/engineering department uses decision making tools.

- What the level of lead time is between development/engineering phases.
- The amount of completed solutions that can be used in the design.
- If there are default solutions that can be used for multiple development/engineering projects.
- Whether there is a clear target set by the customer at the start of a development/engineering project.
- The ratio between the benefits and burdens of development/engineering projects.

What happens to knowledge

Similar to the waste of a development/engineering process is the knowledge of such process ambiguous. As with the waste of a development/engineering process, there is an indistinctness between knowledge for the company as a whole and knowledge for the development/engineering project. However it differs from the ambiguity with waste, because the focus is mainly on the documentation of knowledge for future projects. The measurement tool will concentrate on the knowledge for the company as a whole. To assess this knowledge documentation the following objectives need to be measured by the tool:

- To what extent knowledge is captured and/or documented.
- If there are guidelines for the documentation of knowledge.
- If knowledge is captured and/or documented during a development/engineering project.
- If there is existing, accessible information that is usable during development/engineering projects.
- To what extent documentation from past projects is used for current projects.

4.5 Creating the questionnaire

Based on the criteria that are established in the previous chapter statements can be drafted for the Lean PD efficiency tool. There are statements drafted for each process area and performance indicator. While statements are drafted for performance indicators they are placed at the most appropriate process area. This is done in order to prevent that the participant has the feeling that he/she is questioned about the same subject several times. This could lead to unwillingness from the participant to complete the questionnaire. In cases where a statement is suitable for more than one process area the most appropriate process area is used. The different process areas are divided in to categories. This is done to guide the participant through the questionnaire. The categories also provides the particpants with a scope about the statements.

All questions use the same five point Likert-scale. The participants are asked to indicate to what extent they agree or disagree towards the proposed statement. They have the following options:

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

While the Lean PD efficiency tool is focussed on measuring the efficiency in product development, most persons working in these environments do not envision themselves as designers. They envision themselves as engineers or developers. Therefore instead of using the term design project, the phrase development/engineering project is used. The final questionnaire is added in appendix A.

Set-based concurrent engineering

The statements for SBCE are divided into three different categories. These are: statements about the start of a development/engineering project, statements about the structure of a development/engineering project and statements about testing and decision making.

The statements about the start of a development/engineering project are:

- The desired outcome of a development/engineering project is clearly formulated by the customer.
- At the start of a development/engineering project as few constraints as possible are set.
- During a project, the list of constraints will be expanded.
- Development/engineering projects are divided in (sub) systems.
- For every (sub)system, multiple concepts are developed/engineered.
- For every (sub)system, one concept is developed/engineered.

The statements about the structure of development/engineering project are:

- All (sub)systems are developed independently from each other. Interfaces among (sub) systems are not taken into account.
- The most important (sub) system is the first system to be developed/engineered. The remaining (sub)systems are adjusted to suit the most important (sub)system.
- Intersections between (sub) systems are the starting point of a development/engineering project. When (sub)systems overlap, the best solution for the total project is applied.

The statements about testing and decision making in a development/engineering project are:

- A newly developed/engineered product/machine/equipment/(sub)system is tested to evaluate specifications.
- A new developed/engineered product/machine/equipment/(sub)system is tested beyond its specifications.
- Concepts of (sub)systems are very detailed at the moment of making a selection.
- Concepts of (sub)systems are at an early stage of development at the moment of making a selection.
- A concept for a (sub)system is selected based on the experience and common knowledge of the development/engineering team.
- A concept for a (sub)system is selected based on test, analysis and prototypes.
- A concept for a (sub)system is selected based on repeatedly testing, analysing and making prototypes. This process is repeated until one concept remains.
- Once one concept of a (sub) system is selected, the decision is not reversed.
- Development/engineering is supported by the application of tools (e.g. FMEA) to make decisions on a solid basis.

- Decisions are made before deadlines even if there is not enough information for making a good decision
- Decisions are only made if there is a throughout understanding of their implications.
- Decisions are postponed until all necessary information is available for making them

Focus on gaining knowledge

The statements about gaining knowledge are divided into two separate categories. These are: statements about gained knowledge and the in the company available knowledge and statements about the process for gained knowledge and the in the company available knowledge.

The statements about gained knowledge in a development/engineering project and the in the company available knowledge are:

- Knowledge is saved in documents (Word/Powerpoint) in databases.
- Knowledge is saved using standardized documents.
- Knowledge is saved as general knowledge like trade-off curves and parametric design drawings.
- Knowledge that is acquired during a project is not captured.
- Knowledge that is acquired during a project is captured, evaluated and shared.
- If a problem in a development/engineering project is resolved the solution will be documented.
- Employees are stimulated to and rewarded for creating new knowledge.

The statements about the process for gained knowledge in a development/engineering project and the in the company available knowledge are:

- The learning process for gained knowledge is not captured.
- The learning process for gained knowledge is captured, evaluated and shared.
- The learning process for gained knowledge is saved in documents (Word/Powerpoint) in databases.
- The learning process for gained knowledge is saved using standardized documents.
- The learning process for gained knowledge is saved as general knowledge like trade-off curves and parametric design drawings.
- If a problem in a development/engineering project is resolved the (learning) process behind the solution will be documented.
- The creation of new knowledge is not stimulated or rewarded.

Cadenced flow & knowledge pull

The statements about cadenced flow & knowledge pull are divided in to five different categories. These are: statements about the standardization, statements about rework, statements about planning, statement about the composition of the teams and statements about outside influences.

The statements about the standardization of a development/engineering project are:

- The development/engineering process is well formalized and documented and it is used by project managers to guide the developers/engineers.
- Project gates are defined by concrete results that must be available before the deadline.
- Standardized (sub)systems are used for development/engineering and implemented in

new developed/engineered products/machines/equipment/(sub)systems.
- Standardized processes are used during the development/engineering project.
- Standardized development/engineering techniques are used during the development/ engineering project.

The statements about rework in a development/engineering project are:
- There is rework during the development/engineering project.
- During a development/engineering project there is rework due to changes in the requirements provide by the customer.
- During a development/engineering project there is rework due to communication issues.
- During a development/engineering project there is rework due to solutions that are not feasible.

The statements about the planning of a development/engineering project are:
- The planning of a development/engineering process is completely fixed from the beginning.
- The planning of a development/engineering process is adjusted during the process.
- Projects are not organized based on decisions gates but on regular evaluation meetings.
- The schedules planed on fore hand for a development/engineering process are always met.
- The scheduled time for a development/engineering project is always sufficient.
- The planning of a development/engineering process is created by the development/ engineering team.
- The planning of a development/engineering process is provided by the manager of the development/engineering team.
- The planning of a development/engineering process is provided by an employee/a planner who is not involved in the project.
- The planning of a development/engineering project is used to make a cost benefit analysis for the project.
- A project is only started if there is a good outcome of a cost benefit analysis.

The statements about the composition of development/engineering teams are:
- The development/engineering team always consists of the same persons.
- The development/engineering team is based on a core team and will be adjusted to the assignment.
- For each assignment the development/engineering team is varied, members are selected according to the assignment.

The statements about outside influence in a development/engineering project are:
- R&D is actively involved in the development/engineering project.
- New techniques from R&D are leading in development/engineering.
- Customer values are updated frequently.
- Customer values are used to improve development/engineering.
- Customer values are not used in development/ engineering.

Chapter 5 – Evaluation

A design needs to be evaluated in order to be able to conclude if it is successful or unsuccessful. The Lean PD efficiency tool needs to meet the criteria set in the design brief and needs to be practical for real world use. Each criteria discovered by the evaluation of the process areas and performance indicators is covered in the questionnaire with a question. However to be able to conclude if these questions are adequate and provide the right information the tool needs to be thoroughly evaluated. Also the practicality of the tool needs to be assessed. If the tool provides the correct information but no one is willing to use the tool, the tool will be useless.
In order to evaluate the tool an evaluation strategy has been created, this strategy is described in chapter 5.1. In chapter 5.2 the results of the evaluations are discussed and in chapter 5.3 conclusions resulting from the evaluation are drawn.

5.1 Evaluation strategy

As is stated in chapter 3.4 the success criteria are distinguished in criteria that focus on the usability of the tool and criteria that focus on the usefulness of the tool. In order to assess if the tool usable the way the tool is used needs to be evaluated. For the usefulness of the tool the comparability of the tool with the reality and the applicability of the tool for companies need to be evaluated. This leads to three different levels of evaluation:

1. The way the questionnaire is used
2. The comparability of the tool with the reality
3. The applicability of the tool for companies

In order to be able to carry out this evaluation the tool needs to be tested at different companies. The companies that are used are selected because there are currently other students of the University of Twente that are performing assignments based on Lean for these companies. This results in easy access and a guaranteed in-house expert on the subject of Lean. The results from the questionnaire can be found in appendix B.

The first level of evaluation

First of all the way the questionnaire is used needs to be evaluated. Therefore the time it takes to fill in the questionnaire needs to be documented and any question that arises during the questionnaire need to be documented. These questions can be divided in different categories. This is done to be able to assess where the questionnaire could be improved. These categories correspond with the criteria for the usability set in chapter 3.4. The categories are:

- Terms used in the tool.
- Formulation of the questions/statements
- Usage of the tool
- Applicability towards the company
- Applicability towards the correlated subject

Besides the questions that can arise during the questionnaire the time that is needed to fill in the questionnaire needs to be documented. This documentation is provided by the other students from the University of Twente who are currently placed at the company. For the documentation of the questions and time an evaluation form (appendix C) is used, which uses the different categories to document the questions.

The second level of evaluation

The second level of evaluation needs to evaluate the comparability of the tool with the reality. This is done in two different ways. One approach is comparing the results provided by the tool from in-house experts on Lean with the results provided by the tool from normal employees. To achieve this the students from the University of Twente who are researching Lean and are currently placed at the used companies have provided their results from the tool. The other approach is based on feedback provided by the in-house experts, they can compare their answers and the questions with their perceived reality. This level of evaluation covers three criteria from the criteria for usefulness, set in chapter 3.4. These criteria are:

- The tool needs to be applicable on development/engineering departments that focus on the realisation of existing concepts.
- The tool needs to be suitable for companies that work with multidisciplinary development/engineering departments, consisting of at least three different disciplines.

While the second level of evaluation has two main criteria, it can also be used to cover aspects of the criteria covered by the third level of evaluation. However the second level alone is not enough to fully cover these criteria.

The third level of evaluation

The last level for the evaluation of the tool can be achieved by collecting data from companies, for example by measuring the Lean maturity by observation. The results from the observation should be compared with the data resulting from the tool. For this thesis the focus is on the first two forms of evaluation because of the time it will take to execute the last level of evaluation.

While the statements in the questionnaire cover each criteria discovered by the evaluation of the process areas and performance indicators, this level of evaluation would conclude if the tool does indeed match the criteria for usefulness, set in chapter 3.4. The criteria this level of evaluation should cover are:

- The tool measures the extent to which set-based concurrent engineering is applied by a development/engineering department.
- The tool measure the amount of waste (scatter, hand-off and wishful thinking) the development/engineering process entails of a development/engineering department.
- The tool measures the use of flow & knowledge pull in a development/engineering department.
- The tool maps the structure of the development/engineering process in a development/engineering department.
- The tool determines how knowledge is handled by a development/engineering department.

5.2 Evaluation results

Most criteria form the design brief are covered by the evaluation. However there are some criteria that are not covered. These criteria are: if the tool takes the difference between efficiency of a project and efficiency of a company into account and if the tool uses a maximum of 30 capabilities. If these criteria are met can be determined by analysing the tool. The criteria about the efficiency is covered by the analysis of the waste performance indicator in chapter 4.4. The waste is the main aspect of efficiency that can be applied to the whole company, in chapter 4.4 the choice is made to only focus on the waste for a project. This is done because it cannot be determined if, for example, wasted knowledge for a project will be used for another project in the future. The criteria about the maximum amount of capabilities is covered by the fact that the tool uses only three of the five process areas used by Eshuis (2015). In total all process areas added up to 36 capabilities, the three used process areas add up to 24 capabilities.

The criteria that are covered by the evaluation are measured during the first and second level. However it needs to be stated that the evaluation of the tool had a low response. In total three participants completed the questionnaire, two of the participants were in-house experts. This means that the evaluation will give an indication about the successfulness of the tool, however definitive conclusions cannot be drawn.

First level

During the first level of evaluation mainly questions about the formulation of the statements arose. In total there were four remarks about the formulation of the statements, one remark about the applicability of the questions towards the correlated subject, one remark about the applicability of the questions in the tool towards the company and one general remark about the questionnaire. The average time used to fill in the questionnaire equals 21 minutes and 40 seconds. The general remark about the questionnaire was that questionnaire is very long and that several questions are alike. This means that the tool does not meet the criteria where the questionnaire needs to be completed within a maximum of 15 minutes. Also the general remark creates doubt about the general usability of the tool. In order to determine if the general usability of the tool is at stake, besides the large exceedance of the time limit, the remarks need to be reviewed.

Remarks about the formulation of the statements

Remark 1

Statement: Intersections between (sub) systems are the starting point of a development/ engineering project. When (sub)systems overlap, the best solution for the total project is applied.

This statement should be split up. This because while one part of the statement may be true the other part of the statement does not have to be true subsequently.

Remark 2

Statement: Knowledge that is acquired during a project is not captured.

The statement is not clear. The participant does not know what is meant.

Remark 3
Statement: The creation of new knowledge is not stimulated or rewarded.
Statement: Employees are stimulated to and rewarded for creating new knowledge.

The statements are to comparable. The participant has the feeling answering the same question twice.

Remark 4
Statement: The desired outcome of a development/engineering project is clearly formulated by the customer.

Depending on whom this customer is you can answer with yes or no. Is said customer the final consumer than often this customer is involved but is not the one who will know what the final product should look like, for the mere fact that they will not know what an innovative (new) product will look like. Now if the customer is another department such as Management and logistics, the answer is "very much agree" for M&L is involved in the determination of a project.

Remark about the applicability of the questions towards the correlated subject

Statement: The planning of a development/engineering project is used to make a cost benefit analysis for the project

It is clear that the planning influences the Lean efficiency, however the cost benefit analysis influences the effectivity aspect of Lean.

Remark about the applicability of the questions towards the company

Statement: Concepts of (sub)systems are very detailed at the moment of making a selection

This question strongly relates to whether I develop multiple concepts. I do not, so this question is not relevant. possible solution: place this question next to the multiple concepts question".

Evaluation of remarks

The remarks show that there is room for improvement. Especially the formulation of the statements can improve. This can be done by altering the statements or by providing more information and context about the statements. Subsequently the questionnaire can become more interactive. If the answer to a statement leads to the exclusion of another statement, this statement could be automatically be removed from the questionnaire. The score for this statement would be the lowest by default since it was not applicable.

Results of the Lean PD efficiency tool

The Lean PD efficiency scores resulting from the questionnaire are quite high. This is remarkable because most research and implementation of Lean PD is focussed on the effectivity part of Lean. However according to Eshuis (2015) this can be explained by the similarities of Lean PD with other product development methods. The highest score of the participants is 3.1 figure 13 which corresponds with the third level of the SAUCE scale: Unstructured - The company has started implementing the Lean practices in its PDP following an informal method. According to the statement of Eshuis (2015) this can also be a result of the similarities between Lean PD and other product development methods.

As can be seen in figure 13 the scores from the process areas are reflected in the overall Lean PD efficiency score. What is remarkable is the overall low score for focus on gaining knowledge. Each participant scored low on this process area. This implies that the involved companies can gain the most in this area or that the tool does not cover this process area correctly. However due to the lower weight of this process area, the influence of the low scores in the overall score is limited. This means that the involved companies can probably gain the most on this process area in order to become more Lean in their product development environment.

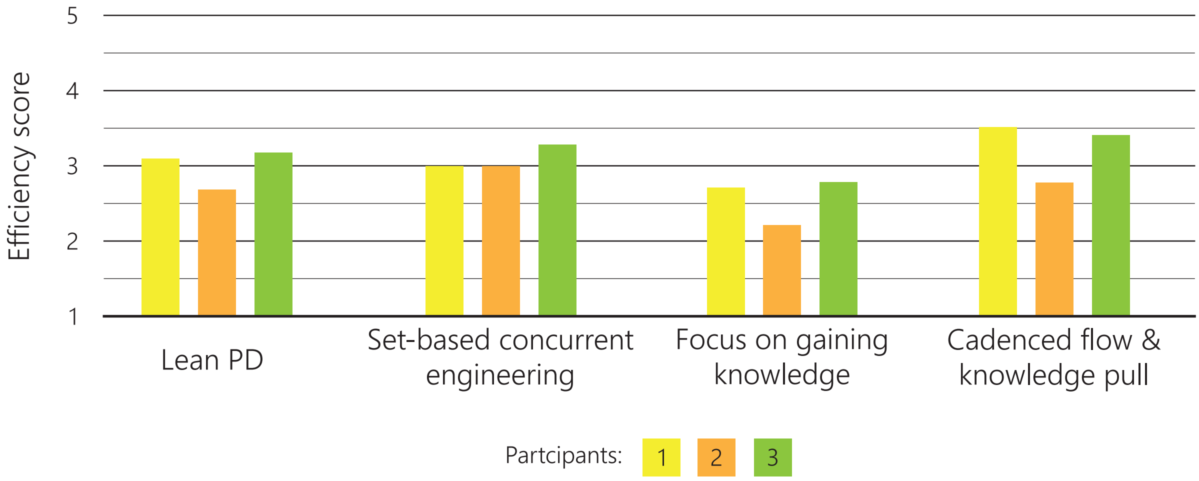

Figure 13. The efficiency score for Lean PD

Second level

For the first approach of the second level of evaluation it is necessary to calculate the scores resulting from the questionnaire from both the in-house experts and the normal employees. However only from one company both the in-house expert and a normal employee completed the questionnaire. While this gives insight if the tool could be working correctly there is not a statistical base on which hard conclusions can be based. The comparison between the scores looks promising. The final score of both the in-house expert and the normal employee equals the third level on the SAUCE scale.

Process Areas	Expert	Normal Employee
Set-based concurent engineering score	3	3.29
Focus on gaining knowledge score	2.71	2.79
Cadenced flow & knowledge pull score	3.52	3.41
Total Lean PD efficiency score	**3.10**	**3.18**

Table 5. Scores on the SAUCE scale for the Expert and normal Employee

As can be seen in table 5 the scores between the expert and normal employee do not exceed each other with more than 0.29 for the process areas and not more than 0.08 for the total score. This is a relatively small difference.

The other approach, the feedback provided by the in-house experts, did not reveal issues which raised doubts concerning the applicability on development/engineering departments or if the tool is suitable for companies that work with multidisciplinary development/engineering departments. As stated in chapter 5.1 in the explanation of the second level of evaluation, some aspects of the third level of evaluation can be partially be covered by the second level. This can be done through the provided feedback. The areas which the tool should cover where explained to the experts. After the completion of the questionnaire there were no remarks about the areas the tool should cover. A very conservative assumption can be made that the tool might meet the criteria that can be measured by the third level of evaluation. However in order to conclude this with certainty the third level of evaluation has to be performed.

5.3 Evaluation conclusion

In the end the Lean PD efficiency tool should meet the criteria set in chapter 3.4. However the tool does not meet all criteria. The criteria that are entirely met based on the evaluation are the criteria about the terms in the tool, the usage of the tool, the applicability on R&D departments, the suitability for companies that work with multidisciplinary departments, the maximum amount of capabilities and the criteria about the difference of efficiency between projects and companies. While there are remarks about the language and phrasing of statements in the questionnaire, no statement is named twice in the remarks. Subsequently the remarks can be solved with minor adjustments, like altering the statements or by providing more context. Also the remark about the applicability of the tool towards the correlated Lean subject can be solved by providing some context. The main issues that emerge in the first evaluation level are about the applicability of the tool towards the company and the time that is needed to fill in the questionnaire. While there is only one remark about the applicability of the tool towards the company, it remains an important issue. When the applicability is doubted this can result in unwillingness to complete the questionnaire. The same applies to the exceedance of the time limit. While the second level of evaluation does not raise any major issues, the evaluation does not provide a statistical base to support the outcome of the evaluation. The outcome of the second level is only based on feedback from the experts and one case in which the expert could be compared with a normal employee. As stated before third level of evaluation is not performed. With the results of the second level of evaluation a very conservative assumption can be made that the criteria of the third level will probably be met.

Chapter 6 - Conclusions

This study was focused on developing a measurement instrument in order to support the development of a training and consultancy materials for companies in order to improve the NPD efficiency of their R&D departments. This measurement instrument should give insight in the implementation of several Lean techniques at these companies and give insight in the NPD challenges of the companies. Therefore a literature study was performed to get an insight in Lean, especially focused on Lean Product Development, and the structure of design processes. Five different core enablers for Lean PD were found. Further study of these core enablers revealed a strong correlation between three of the five core enablers and the efficiency in product development. These core enablers are: set-based concurrent engineering, focus on creating knowledge and cadenced flow & knowledge pull. The study towards the structure of design processes shows that the structure is far from linear. However the structure can be captured using a DPU.

Supported by the knowledge provided by the literature study the development of tool was started. Therefore an analysis of an existing model was performed. This resulted in a maximum amount of 30 capabilities the tool should use, an usable measurement scale for Lean PD efficiency: the SAUCE scale, and insight in how to guide and question the participants of the tool. The guidance and questioning was an important aspect, because the participants of the existing model were forced to make hard choices that could result in a distorted view off the reality. The next step in the development was to establish the boundaries of the tool, followed by making an analogy between a manufacturing process and a design process. These steps combined resulted in a design brief for the Lean PD efficiency tool.

This exploration phase is followed by the real development of the tool. Therefore a starting point, a method of questioning and a scoring model were determined. The method of questioning is based on using statements which provided room for gradual distinction in answering for the participant. The scoring method that was developed is based on the SAUCE scale discovered during the analysis of the existing Lean maturity model. Based on insights gained from analysing process areas and performance indicators provided by the starting point the questionnaire for the tool could be drafted.

The tool was evaluated by an evaluation strategy based on three different levels. The evaluation revealed that while the tool looks promising there is room for improvement. While some criteria that are not met can be accomplished by making slight changes to the questioning, other criteria need a more drastic adjustment to the tool. Especially the length of the questionnaire needs to be evaluated and assessed to determine how the participants can complete the questionnaire in less time. The main goal of this study was to develop a tool that measures the Lean PD efficiency in R&D departments. While there is room for improvement, the Lean PD efficiency tool takes the first steps in order to reach that goal. The Lean PD efficiency tool should be adjusted an re-evaluated through all three evaluation levels to reach that goal.

Chapter 7 - Recommendations

As stated in the conclusion the Lean PD efficiency tool needs to be adjusted in order to meet the criteria set in the design brief. The main issue of the tool is the length of the questionnaire, before the third level of evaluation is performed this needs to be solved. This can be achieved by making the questionnaire more condensed. This can be done by eliminating statements that are too much alike. For example statements that approach the same issue ones from a negative view and ones from a positive view. While this approach is a good practices in questionnaires to filter unusable/fake participants, the potential time gain is more important. The amount of unusable/fake participants will probably already be low because of the environment in which the tool will probably be deployed. Most employees will probably acknowledge the importance of the questionnaire and will probably not turn in false answered questionnaires.

A more study based approach to improve on the length of the questionnaire is by performing an additional literature study on other product development methods and their correlation with Lean. This may provide new ways to approach the aspects of Lean. These new ways may support a different, shorter, route of questioning.

When the tool is adjusted it is recommended that the first two evaluation steps are repeated before proceeding towards the third evaluation step. If possible a larger response group is strongly advised in order to be able to draw statically supported conclusions. The first two evaluation steps could also be expanded by asking the participant if they focus on (implementing) Lean PD in their department/company. This can give further insight in the validity of the tool. For example if multiple companies score high results but are not focused on Lean PD this may result in reasons to doubt the validity.

Besides the improvements that can be made on the questionnaire, the total tool can also be improved. At this moment the researcher who will use the tool needs to transcribe the results from the questionnaire towards a SAUCE score for each question. Subsequently the scores for each process area and the total score need to be calculated by hand. A closed system that performs these steps automatically would be a huge improvement.

Another improvement could be to implement a help section in the tool. This section could be used to provide the participants with information about Lean PD. This could lead to a more accurate representation of the reality through the responses of the participants. This addition should also be validated to ensure the participants do not become biased.

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Appendix A - Questionnaire

Questionnaire LEAN PD

This questionnaire provides data for research on the efficiency of development/engineering departments in relation to their LEAN PD maturity. All information is processed on a confidential basis and anonymity is guaranteed.

Since the research is focusing on the efficiency aspect of LEAN PD, the focus is on three aspects of LEAN PD. These aspects are: Set based concurrent engineering, Focus on gaining knowledge and cadenced flow & knowledge pull. There are no right or wrong answers to the questions. Please, answer truthfully to the questions. If you are not sure about a question, please answer it to your according to your own judgement. You are free to stop the questionnaire at any time.

Thank you for taking time for helping the research.

Set based concurrent engineering

1. The statements below, are about the start of a development/engineering project. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
The desired outcome of a development/engineering project is clearly formulated by the customer.	○	○	○	○	○
At the start of a development/engineering project as many constraints as possible are set.	○	○	○	○	○
During a project, the list of constraints will be expanded.	○	○	○	○	○
Development/engineering projects are divided in (sub) systems.	○	○	○	○	○
For every (sub)system, multiple concepts are developed/engineered.	○	○	○	○	○
For every (sub)system, one concept is developed/engineered.	○	○	○	○	○

2. The statements below, are about the structure of a development/engineering project. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
All (sub)systems are developed independently from each other. Interfaces among (sub)systems are not taken into account.	○	○	○	○	○
The most important (sub) system is the first system to be developed/engineered. The remaining (sub)systems are adjusted to suit the most important (sub)system.	○	○	○	○	○
Intersections between (sub) systems are the starting point of a development/engineering project. When (sub)systems overlap, the best solution for the total project is applied.	○	○	○	○	○

3. **The statements below, are about the testing and decision making in a development/engineering project. Please indicate to what extent you agree or disagree with the statements.**

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
A newly developed/engineered product/machine/equipment/(sub)system is tested to evaluate specifications.	◯	◯	◯	◯	◯
A new developed/engineered product/machine/equipment/(sub)system is tested beyond its specifications.	◯	◯	◯	◯	◯
Concepts of (sub)systems are very detailed at the moment of making a selection.	◯	◯	◯	◯	◯
Concepts of (sub)systems are at an early stage of development at the moment of making a selection.	◯	◯	◯	◯	◯
A concept for a (sub)system is selected based on the experience and common knowledge of the development/engineering team.	◯	◯	◯	◯	◯
A concept for a (sub)system is selected based on test, analysis and prototypes.	◯	◯	◯	◯	◯
A concept for a (sub)system is selected based on repeatedly testing, analysing and making prototypes. This process is repeated until one concept remains.	◯	◯	◯	◯	◯
Once one concept of a (sub) system is selected, the decision is not reversed.	◯	◯	◯	◯	◯
Development/engineering is supported by the application of tools (e.g. FMEA) to make decisions on a solid basis.	◯	◯	◯	◯	◯
Decisions are made before deadlines even if there is no enough information for making a good decision	◯	◯	◯	◯	◯
Decisions are only made if there is a throughout understanding of their implications.	◯	◯	◯	◯	◯
Decisions are postponed until all necessary information is available for making them	◯	◯	◯	◯	◯

Focus on gaining knowledge

4. The statements below, are about gained knowledge in a development/engineering project and the knowledge available in the company. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Knowledge is saved in documents (Word/Powerpoint) in databases.	○	○	○	○	○
Knowledge is saved using standardized documents.	○	○	○	○	○
Knowledge is saved as general knowledge like trade-off curves and parametric design drawings.	○	○	○	○	○
Knowledge that is acquired during a project is not captured.	○	○	○	○	○
Knowledge that is acquired during a project is captured, evaluated and shared.	○	○	○	○	○
If a problem in a development/engineering project is resolved the solution will be documented.	○	○	○	○	○
Employees are stimulated to and rewarded for creating new knowledge.	○	○	○	○	○

5. The statements below, are about the process for gained knowledge in a development/engineering project and the knowledge available in the company. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
The learning process for gained knowledge is not captured.	○	○	○	○	○
The learning process for gained knowledge is captured, evaluated and shared.	○	○	○	○	○
The learning process for gained knowledge is saved in documents (Word/Powerpoint) in databases.	○	○	○	○	○
The learning process for gained knowledge is saved using standardized documents.	○	○	○	○	○
The learning process for gained knowledge is saved as general knowledge like trade-off curves and parametric design drawings.	○	○	○	○	○
If a problem in a development/engineering project is resolved the (learning) process behind the solution will be documented.	○	○	○	○	○
The creation of new knowledge is not stimulated or rewarded.	○	○	○	○	○

Cadenced flow & knowledge pull

6. The statements below, are about the standardization of a development/engineering project. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
The development/engineering process is well formalized and documented and it is used by project managers to guide the developers/engineers.	○	○	○	○	○
Project gates are defined by concrete results that must be available before the deadline.	○	○	○	○	○
Standardized (sub)systems are used for development/engineering and implemented in new developed/engineered products/machines/equipment/(sub)systems.	○	○	○	○	○
Standardized processes are used during the development/engineering project.	○	○	○	○	○
Standardized development/engineering techniques are used during the development/engineering project.	○	○	○	○	○

7. The statements below, are about the rework in a development/engineering project. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
There is rework during the development/engineering project.	○	○	○	○	○
During a development/engineering project there is rework due to changes in the requirements provide by the customer.	○	○	○	○	○
During a development/engineering project there is rework due to communication issues.	○	○	○	○	○
During a development/engineering project there is rework due to solution’s that are not feasible.	○	○	○	○	○

8. The statements below, are about the planning of a development/engineering project. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
The planning of a development/engineering process is completely fixed from the beginning.	○	○	○	○	○
The planning of a development/engineering process is adjusted during the process.	○	○	○	○	○
Projects are not organized based on decisions gates but on regular evaluation meetings.	○	○	○	○	○
The schedules planed on fore hand for a development/engineering process are always met.	○	○	○	○	○
The scheduled time for a development/engineering project is always sufficient.	○	○	○	○	○
The planning of a development/engineering process is created by the development/engineering team.	○	○	○	○	○
The planning of a development/engineering process is provided by the manager of the development/engineering team.	○	○	○	○	○
The planning of a development/engineering process is provided by an employee/a planner who is not involved in the project.	○	○	○	○	○
The planning of a development/engineering project is used to make a cost benefit analysis for the project.	○	○	○	○	○
A project is only started if there is a good outcome of a cost benefit analysis.	○	○	○	○	○

9. The statements below, are about the composition of development/engineering teams. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
The development/engineering team always consists of the same persons.	○	○	○	○	○
The development/engineering team is based on a core team and will be adjusted to the assignment.	○	○	○	○	○
For each assignment the development/engineering team is varied, members are selected according to the assignment.	○	○	○	○	○

10. The statements below, are about outside influences in a development/engineering project. Please indicate to what extent you agree or disagree with the statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
R&D is actively involved in the development/ engineering project.	◯	◯	◯	◯	◯
New techniques from R&D are leading in development/engineering.	◯	◯	◯	◯	◯
Customer values are updated frequently.	◯	◯	◯	◯	◯
Customer values are used to improve development/engineering.	◯	◯	◯	◯	◯
Customer values are not used in development/ engineering.	◯	◯	◯	◯	◯

Demographic questions

11. How many disciplines are there on average in a development/engineering team?

>10

12. I am a:

○	Engineer
○	Developer
○	Manager
○	Other:

13. The starting point of our engineering/development project is:

○	We start from scratch. There is no concept at the start, only an idea.
○	We start from a concept and engineer/develop it towards an final product.
○	Our starting point is an existing product, we engineer/develop it to improve it.

Appendix B - Results from questionnaire

	Response 1	Response 2	Response 3
SBCE			
Statements about the start of a development/engineering project			
The desired outcome of a development/engineering project is clearly formulated by the customer.	Neither agree nor disagree	Strongly disagree	Neither agree nor disagree
At the start of a development/engineering project as few constraints as possible are set.	Disagree	Disagree	Agree
During a project, the list of constraints will be expanded.	Agree	Disagree	Agree
Development/engineering projects are divided in (sub) systems.	Strongly agree	Agree	Strongly agree
For every (sub)system, multiple concepts are developed/engineered.	Neither agree nor disagree	Agree	Strongly disagree
For every (sub)system, one concept is developed/engineered.	Neither agree nor disagree	Neither agree nor disagree	Strongly agree
Statements about the structure of a development/engineering project.			
All (sub)systems are developed independently from each other. Interfaces among (sub)systems are not taken into account.	Strongly disagree	Neither agree nor disagree	Strongly disagree
The most important (sub) system is the first system to be developed/engineered. The remaining (sub)systems are adjusted to suit the most important (sub)system.	Disagree	Disagree	Neither agree nor disagree
Intersections between (sub) systems are the starting point of a development/engineering project. When (sub)systems overlap, the best solution for the total project is applied.	Agree	Neither agree nor disagree	Agree
Statements about the testing and decision making in a development/engineering project.			
A newly developed/engineered product/machine/equipment/(sub)system is tested to evaluate specifications.	Strongly agree	Agree	Strongly agree
A new developed/engineered product/machine/equipment/(sub)system is tested beyond its specifications.	Neither agree nor disagree	Neither agree nor disagree	Agree
Concepts of (sub)systems are very detailed at the moment of making a selection.	Disagree	Agree	Neither agree nor disagree
Concepts of (sub)systems are at an early stage of development at the moment of making a selection.	Agree	Strongly disagree	Neither agree nor disagree
A concept for a (sub)system is selected based on the experience and common knowledge of the development/engineering team.	Strongly agree	Strongly agree	Neither agree nor disagree
A concept for a (sub)system is selected based on test, analysis and prototypes.	Disagree	Agree	Neither agree nor disagree
A concept for a (sub)system is selected based on repeatedly testing, analysing and making prototypes. This process is repeated until one concept remains.	Strongly disagree	Agree	Neither agree nor disagree
Once one concept of a (sub) system is selected, the decision is not reversed.	Agree	Disagree	Neither agree nor disagree
Development/engineering is supported by the application of tools (e.g. FMEA) to make decisions on a solid basis.	Agree	Agree	Strongly agree
Decisions are made before deadlines even if there is not enough information for making a good decision	Disagree	Strongly agree	Disagree
Decisions are only made if there is a throughout understanding of their implications.	Neither agree nor disagree	Disagree	Neither agree nor disagree
Decisions are postponed until all necessary information is available for making them	Strongly disagree	Strongly disagree	Disagree
Focus on creating knowledge			
Statements about gained knowledge in a development/engineering project and the knowledge available in the company.			
Knowledge is saved in documents (Word/Powerpoint) in databases.	Agree	Strongly agree	Neither agree nor disagree
Knowledge is saved using standardized documents.	Neither agree nor disagree	Strongly disagree	Agree
Knowledge is saved as general knowledge like trade-off curves and parametric design drawings.	Disagree	Strongly disagree	Disagree
Knowledge that is acquired during a project is not captured.	Disagree	Agree	Disagree
Knowledge that is acquired during a project is captured, evaluated and shared.	Disagree	Disagree	Agree
If a problem in a development/engineering project is resolved the solution will be documented.	Agree	Agree	Neither agree nor disagree
Employees are stimulated to and rewarded for creating new knowledge.	Disagree	Strongly disagree	Neither agree nor disagree
Statements aboutt the process for gained knowledge in a development/engineering project and the knowledge available in the company.			
The learning process for gained knowledge is not captured.	Agree	Agree	Neither agree nor disagree
The learning process for gained knowledge is captured, evaluated and shared.	Disagree	Strongly disagree	Neither agree nor disagree
The learning process for gained knowledge is saved in documents (Word/Powerpoint) in databases.	Neither agree nor disagree	Agree	Neither agree nor disagree
The learning process for gained knowledge is saved using standardized documents.	Neither agree nor disagree	Strongly disagree	Neither agree nor disagree
The learning process for gained knowledge is saved as general knowledge like trade-off curves and parametric design drawings.	Disagree	Strongly disagree	Disagree
If a problem in a development/engineering project is resolved the (learning) process behind the solution will be documented.	Disagree	Strongly disagree	Strongly disagree
The creation of new knowledge is not stimulated or rewarded.	Neither agree nor disagree	Strongly disagree	Neither agree nor disagree
Cadenced flow & knowledge pull			
Statements about the standardization of a development/engineering project.			
The development/engineering process is well formalized and documented and it is used by project managers to guide the developers/engineers.	Neither agree nor disagree	Neither agree nor disagree	Agree
Project gates are defined by concrete results that must be available before the deadline.	Strongly agree	Agree	Agree

Appendix C - Evaluation form

Evaluation form

For the evaluation of the LEAN PD questionnaire the way it is used needs to be evaluated. Therefore this evaluation sheet is provided. This evaluation sheet is divided in two parts. The first part can be used to document observations for the evaluation. If there are any uncertainties about the questionnaire or this evaluation form you can always contact me. Please return the evaluation form to me by email.

Observations

The elapsed time can be documented in minutes in the field titled: "Time elapsed". Please document the questions that arise and the answer provided in the corresponding field. If there are questions that do not correlate with a field, please document them in the last field titled: "Other questions".

Time elapsed

Company

Questions about used terms used in the tool.

Questions about the formulation of the questions in the tool.

Questions about how to fill in/use the tool.

Contact info:
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Questions about the applicability of the questions in the tool towards the company.

Questions about the applicability of the questions towards the correlated subject.

Other questions

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