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Human Factors Engineering as a supportive tool for Lean Product Development

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Abstract
Lean Product Development (LPD) is a systematic approach used by enterprises to create streamlined processes and value-added activities. One of the main building blocks in LPD is to define and identify customer value and then deliver that value to the customer. Despite that, we have perceived a number of weaknesses in how LPD works with customer needs and requirements. Especially with respect to how best actively and continuously involve the customers/users in the development process. The area of Human Factors Engineering (HFE) concerns ways of designing with regards to human characteristics, capacities and limitations. In the work it is central to elicit user needs and mediate them into the product development processes, as well as letting the user actively be involved in the process. Therefore, in this paper we argue that HFE can make substantial contribution to the area of LPD.

Keywords: Lean Product Development, Human Factors Engineering, Customer Value, User Involvement, Methods

1 Introduction

Lean Product Development (LPD), is a well-known and systematic approach used by enterprises today to create streamlined processes and value-added activities in the product development process [1, 2]. The main building blocks in LPD are to define and identify customer value, deliver the value and then maintain delivering customer value throughout the product life-cycle. Furthermore, Radeka writes [3, p.21] *"Lean Product Development emphasizes building deep customer knowledge through activities that help us develop customer empathy: the ability to sense customers' stated and unstated needs when they are in their natural environment so that we can make decisions that maximize value for the customer*."

Despite this focus on customer needs, we have perceived LPD-weaknesses in relation to how customer needs and values are defined and delivered, in the manner that LPD is often described in the literature. We believe these weaknesses are obstacles that prevent LPD to function in an optimal way. Our perception is based on experience in the field of product development in several projects both in industry and academia. The first half of this paper will

describe our view of LPD and the five main weaknesses that we have perceived when reflecting over the theory of LPD.

In the second half of this paper we will argue that the area Human Factors Engineering (HFE) can make a substantial contribution to the area of Lean Product Development. Human Factors Engineering (HFE) concerns ways of designing jobs, machines, operations, and work environments so they are compatible with human characteristics, capacities and limitations [4]. When working with HFE it is central to elicit user needs and mediate them into the product development processes, as well as letting the user be actively involved in the process. We will therefore argue that HFE can help counteracting the weaknesses with LPD that will be described in this paper. Our suggestions are based on our experience of applying HFE in product development projects. The paper ends with a discussion and a summary.

2 Lean Product Development

What makes Toyota so successful? Lean Product Development (LPD) or the Lean Product Development System (LPDS) originated from many lean experts asking just that particular question about what the primary methods, principles, and processes are that make Toyota so flourishing [1]. Morgan and Liker [1] identified 13 principles of lean and gathered them into three main groups: process, people, and technology. The underlying message in all principles which also forms the foundation of LPD is "*the importance of appropriately integrating people, processes, tools, and technology to add value to the customer and society*" [1, p.5]. Furthermore Martínez León and Farris [5, p.29] define LPD as "*LPD is viewed as the cross-functional design practices (techniques and tools) that are governed by the philosophical underpinnings of lean thinking – value, value stream, flow, pull and perfection – and can be used (but are not limited) to maximize value and eliminate waste in PD*".

The different approaches to describe lean present mutual principles for LPD and a common view across books and articles, is that a truly lean system is one that continuously improves processes, people, and technology - a focus which is defined as *kaizen* by Toyota. Furthermore, the basic idea of lean is to eliminate waste, focus on value adding activities and seek to maximise the value for the customer [6]. Liker [7] points out that the majority of business processes consist of 90% waste and 10% value adding activities. Radeka [3, p.5] states that "*product developers systematically solve problems to maximize value and minimize waste across the entire system*" and indicates that one of the benefits with LPD is that the developers have the ability to learn more about customer needs and also to translate that into the right products.

There are many aspects of LPD, for example value flow management and the house of lean [8], however this paper specifically focuses on the aspects of Lean Product Development that relate to customer requirements, needs and values. The central questions are:

- What is customer value according to LPD?
- How can customer requirements be defined by using lean principles?

Literature indicates that there are two different aspects on how customer value is defined. On one hand the internal business perspective is used as a definition, whilst on the other hand customer value is defined from an external customer perspective concerning the end-users use of the product. According to Radeka [3, p.15], Jim Womack defines customer value entirely from the customer's perspective: "*The right product to the market at the right time and at the right price*". Bicheno and Holweg [6, p.18] quotes Saliba and Fisher, also from an external

customer perspective, defining that "*one straightforward interpretation of value is Perceived Benefit/Perceived Sacrifices*". Furthermore, Mascitelli [9, p.59] proposes the following definition of customer value-added activities: "*A design/development activity is value-added if it transforms a new product design (or the essential deliverables needed to commercialize it) such that the product's profit margin and/or market share are positively impacted*". Mascitelli [9] thereby defines value from a business internal perspective. It is first of all important to understand how the targeted customer perceives and identifies values itself [10]. Butz and Goodstein [11, p.63] state, also from a business internal perspective, that "*The more a producer adds value to a product or service, the more distinctive that product or service becomes to the customer. This in turn can lead to higher prices and, presumably, higher margins and greater profits*".

In this paper the external way of defining customer value will be used and more explicit the quote by Woodruff [12, p.142]: "*Customer value is a customer's perceived preference for and evaluation of those product attributes, attribute performances, and consequences arising from use that facilitate (or block) achieving the customer's goals and purposes in use situations*". Customer value is consequently defined in this article with a focus on the **use** of products or services. We have a wide definition of customers, as Hines et.al. [13, p.872] who suggests that "*views of each of the players (and possibly more) need to be considered*".

3 Weaknesses in LPD in relation to the customer/user

We have perceived five main weaknesses in LPD in relation to customer needs and values in the manner that LPD often is described in the literature. In this section each weakness will be discussed individually and our interpretation will then be given as a statement.

When reading literature about implementing, executing and developing LPD processes and lean thinking in an organization we, most often, perceive the importance of defining customer requirements and values in the early phase of the product development process. We also perceive the idea that the defined customer requirements can cover the complete problem, so the customer requirements and values are often taken for granted once defined and are infrequently revised downstream during the product development process. This is counterintuitive based on our experience with product development; where continuous work with customer requirements is needed. Furthermore, it is seldom mentioned that customer requirements and values may change during the product development process and therefore need to be updated along the process.

One of the few references found, Schuh et.al. [14, p.1134], wrote about the importance of revising the requirements throughout the development process, which we also find crucial to succeed. "*The first process includes the transformation of customer needs into detailed technical requirements at the beginning of a project. The second process includes the handling of requirements during the development process. In order to deal with changing and new requirements, a consequent configuration management and change management has to be included as well*". It can however be discussed whether or not Schuh et.al. include both customer and technical requirements in the second process, or if it is just the technical requirements that need to be managed. The first two weaknesses with LPD that we have perceived can be formulated into the following two statements:

- **Weakness 1:** Customer requirements are rarely changed or revised during the process i.e. they are static during the process.

- **Weakness 2:** It is often assumed that all customer requirements can be captured and defined in the start of the project.

Our next perceived weakness in LPD relates to the transformation of customer needs and requirements to a product that delivers customer value. We often assume that if customer requirements are caught correctly, early in the development phase, then it will automatically generate an end product that fulfils those needs and creates customer value. Authors that address this issue are Schuh et.al. [14, p.1134] which write, "*A frequent cause for wrong decisions and late iterations is the missing transparency of customer values and needs as well as resulting project objectives. Even if customer requirements are known, they run out of focus during project very often*".

This weakness has also been identified by Jim Womack who wrote [2, p.8] "*I have long felt that a great weakness of the lean movement is that we tend to take customer value as given, asking how we can provide more value as we currently define it, at lower cost with higher quality and more rapid response to changing demand. This is as far as it goes. But what if the customer wants something fundamentally different from what our organizations are now providing?*". We can also see a tendency, where the recommended approach is to define customer value as a set of customer requirements in a quantifying way, instead of including the users in the product development process. We believe it is very difficult to develop a complete specification in written format, covering all demands and requirements that the user might have. We describe this weakness as:

- **Weakness 3:** It is often assumed that if customer requirements are gathered correctly, this will automatically generate a product with high customer value.

The next weakness we have perceived relates to the methods used to handle customer needs and requirements during the development process. The literature suggests several systematic methods to identify and elicit customer values, such as gemba walks, interviews, questionnaires, prototypes, focus groups, contextual inquiry, antenna shop internal engineering assessment, field value-in-use assessment, benchmarks, prototypes, QFD, and kano analysis [10, 13]. These methods mostly focus on the gathering of customer needs and requirements. However it is not often explained how customers can be continuously involved and integrated in the process, nor how the methodologies presented iteratively can be used in the development process and continuously ensure the right focus.

We perceive that presented methods in the literature to handle the customer needs and values are mainly considered in the early stages of the process. This is probably an effect of the weaknesses described earlier. Flores et.al. concluded [10, p.9] in an study, that covered how customer value was captured in 11 different companies with LPD, that "*The marketing department is the main responsible for capturing and analyzing customer value whereas requirement engineers and product engineers are barely involved*". We regard this as an indicator that the continuous work with customer value during the LPD-process needs to be improved.

An author that suggests a procedure that actually involves the customers during the development process is Mascitelli [15, p.67], who writes about LPD that "*There is an optimal design for every problem, and depending on how well-defined your customer or market segment is, you can home in on an ideal product solution that will maximize value; performance delivered at a given price*". He further states that "*A systematic process for the translation of customer need and benefits into a language of product design is needed*" and

presents a model for the gathering of customer feedback throughout the product development process, by using iterative prototyping that allows customers to give feedback and criticism. In 2007 Mascitelli also presented this systematic approach with the purpose to avoid developing products that either undershoot or overshoot the needs of the market [16].

Furthermore after gathering the customer needs and requirements, the LPD literature mostly focuses on reduction of waste and creation of value flow in the processes. It is rarely mentioned how to transform the user needs to products with high user values. It can be argued that this is a task for other fields, such as mechanical engineering or software development, but we think that LPD can gain by focusing more on how to create customer value during the whole development process and not only in the early stages. We summarise the argumentation above in the fourth weakness:

- **Weakness 4:** There is not enough emphasis on the procedure and methods to transform customer needs and requirements to a product with customer value.

Our last perceived weakness regards the documentation and communication of the customer needs and values in the development project, to ensure a unified accurate picture and understanding of the customer requirements throughout the process. Morgan and Liker [1] (p. 30-32) explain that the chief engineer plays an important and crucial role in LPD when it comes to the interpretation and understanding of customer requirements, as well as documenting and communicating customer needs to the product development team. The process of delivering value to the customer starts with the chief engineer writing a concept paper. Many people give their input but it is issued by the chief engineer. This is a *direct order document* and when the concept is approved the next step is to develop specific objectives for all teams involved in the development. Team members are judged partly on their ability to hit the targets. Morgan and Liker (p.36) write that "*Excellent product development requires that the program leadership has a process for clearly communicating specific, detailed goals that are aligned throughout the program and that leadership engages all functional groups to participate in delivering customer-defined value*". How is this actually performed? What does the process look like in order to deliver customer-defined value throughout the process? How precise are the goals aligned? How are the users involved? What happens if customer requirements change over time?

We see this approach, with the a chief engineer ultimately being responsible for delivering value to the customer, documenting, sharing and ensuring everyone involved really understands the customer requirements and needs during the development phase as a huge challenge. The chief engineer should also have "*a visceral feel for what the customer wants*" [1, p.119], which we consider overwhelming for one individual. We also feel that there is a need for means to distribute the documentation and application of the knowledge.

In most lean literature it is stated that it is important that everyone involved shares the same view. However it is rarely defined exactly how the customer requirements shall be documented and communicated internally to ensure a common view and understanding throughout the program, is achieved for everyone involved. Despite this, the authors Flores et.al. [10, p.1] claim that "*There are several methods to capture and analyze customer values as well as tool and techniques to represent them in product design*", we summarise this as:

- **Weakness 5:** There is a low focus on how to document and communicate the customer needs and values within the development project.

We believe that a more tailor made approach to define, communicate and explore customer values throughout the entire product development process ought to exist - a specific approach that addresses customer value and needs not only in the beginning, but also during and in the end of the product development process. A process that continuously collects as well as delivers customer value during the entire development process must exist. Our suggestion is to integrate processes, methods and theory from the field of Human Factors Engineering.

4 Human Factors Engineering

HFE is the engineering application of the field of ergonomics and human factors. The International Ergonomic Society [17] defines ergonomics and human factors more precisely as *"the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance."* Interesting to note is that the optimization of human well-being and overall system performance can be seen as a goal to eliminate waste towards the end user.

Human Factors Engineering is in turn defined as an approach that "*... applies information about human abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable and effective human use.*" Chapanis [4, p.2]. To be able to achieve this, processes and methods to design products adapted to the human, are central [18, 19]. Especially interesting here is theory, tools and methods to elicit user requirements and include them in the development process [20-22].

Compared to the nomenclature used in LPD there are two things to be observed. The first is that in HFE it is important to separate customer and user, whilst the customer buys the product, it is the user who uses the product. The second thing is when HFE refers to a user they are humans i.e. HFE focus on humans in their roles as users.

In the Lean Product Development System Model, Morgan and Liker [1] presents 13 basic principles to LPD. When looking at them in relation to HFE the first two principles show a clear connection. Principle 1: "*Establish Customer-Defined Value to Separate Value-Added Activity form Waste*" and Principle 2: "*Front-Load the Product Development Process While There is Maximum Design Space to explore Alternative Solutions Thoroughly*".

Regarding principle 1 HFE has a fundamental focus on the value in the use of products. Value is seen in a broad sense as being, productive, safe, comfortable, and effective to use. Jim Womack [2, p.11] introduces the concept of Lean Consumption that highlights what the organisation should consider to achieve a focus on customer-defined value:

- *"Solve the customer's problem completely, by ensuring that everything works the first time.*
- *Don't waste the consumer´s time.*
- *Provide exactly what the customer wants.*
- *Provide value where the customer wants.*
- *Provide value when the customer wants.*
- *Reduce the number of problems customers need to solve."*

Regarding product use, the points from Lean Consumption fits very well as a means to achieve the goal of Ergonomics and Human Factors. The goal is: to optimise system performance and human well-being. Hence any product development process that integrates HFE will get a natural focus on customer value.

Regarding principle 2, HFE emphasises the need to study and understand the user as well as the design activities that focus on the use and user interface, before the technical development of the product. This focus makes any product development process that integrates HFE more front-loaded. LPD and HFE have accordingly a good congruence in particular areas at a high level of abstraction. However to make HFE of real use in LPD there needs to be a practical implication, which will be described in the next section of the paper.

5 How HFE can support LPD

Generally HFE can support LPD since the designed products will become better adapted to humans, with higher system performance and higher human well-being. The practical contribution that HFE offers is an approach that continuously considers the user and the use throughout the whole product development processes. We argue that HFE can counteract the weaknesses of LPD stated above, by applying continuous involvement of the user/customers in an iterative manner. Meaning involving the user in suitable ways, by both receiving input to the design and to obtain feedback on design suggestion (and sometimes also directly involve the user in the design), in each step of the development process from the beginning to the end. The idea is that user/customer value is not only dependent on the gathering of user/customer needs but also on how this is transferred into the design of the product.

As described earlier a main focus for LPD is to reduce waste in the product development process. Radeka [3, p.18] states seven common wastes in product development and regarding this HFE can contribute by avoiding "*Design loopbacks*" and "*Insufficient customer empathy*". By developing the design, with a focus on the user and the use, the possibility that a satisfying product is designed and that the product fits the user/customer needs and expectations increases. We argue that HFE can help LPD to reduce waste in the use situation, hence increasing the user/customer value. We consider four areas within HFE to be of special interest for LPD. The importance of them depends on the particular development project.

- Methods to document and communicate user needs
- Theory for designing products adapted to the human
- Methods to involve the users in the design
- Methods to evaluate the product from the user perspective

5.1 Methods to document and communicate user needs

LPD stresses that all developers should keep in mind the customer's / user's best, which requires that the developers have this knowledge available. In LPD the common way to document user needs and user information is in tables, diagrams and matrices. These means are also used within HFE, yet HFE provides additional methods that make the user and the use more visible for the developers throughout the project. Examples of methods are:

- User Profile - objective description of user characteristics
- Persona - subjective description of prototypical users
- Task Analysis - descriptions of the contents in the use
- Use Scenarios - descriptions of the situations for the use

These methods can keep the user vivid and prevent the user from being reduced to only data in a table or matrix. This will make the user more present for the developers. The use is often of holistic character where the combination of fulfilled user requirements adds user value and therefore it is important to show the user needs in an integrated way. The methods also make it easier to see relations between user needs and design solutions.

5.2 Theory for designing products adapted to the human

The foundation for Ergonomics and Human Factors is the knowledge about how products and work places should be designed to work well with humans. There exists comprehensive knowledge, adapted to the engineering work, regarding both users' cognitive [23] and physical [24] characteristics. Three areas that we consider especially relevant are:

- Usability - how a user understands and interacts with products
- Subjective aspects - how users appreciate the use and emotional relation to the products
- Physical ergonomics and anthropometrics - how to practically fit the product to the user

If the developed product does not fit the body and/or cognition of the user/customer, the user/customer value will undoubtedly be affected negatively. The theory also acts as support in translating the needs to design solutions and selecting between different design solutions. Further advantage with this theory is that it increases the probability that unspoken user needs will be considered.

5.3 Methods to involve the users in the design

LPD emphasises the customer/user value to a large extent, but making the user participate actively in the development is rarely mentioned. In HFE it has been observed that involvement of the users leads to better products [20] and it is easier to have user focused development when including users. In addition to involving the users in requirement elicitation and product evaluations there are other approaches to involve the users in the design:

- Reference groups - an advisory group that consists of users that supports the project
- User brainstorming – users are actively involved in the creation of new ideas
- Co-designer - users support the developers directly in the design work

The big advantage of including the users in development work is that not everything needs to be caught in the beginning of the project, rather that the understanding of customer value grows gradually with the product design. The development process is not as dependent on the assumption that all user needs/values are identified in the early stages, making it easier for the project to detect and react to changes in the user needs/values.

5.4 Methods to evaluate the product from the user perspective

To ensure that the user can interact well with the developed products, there is a need to evaluate the product from a user perspective. Within HFE there exists a large number of methods to evaluate product representations, ranging from a rough sketch to working prototypes. The methods can be categorized as analytical, expert or user [25].

- An analytical evaluation applies a systematic and structured process in the assessment
- An expert evaluation relies on experts in the field being able to use their general knowledge and experience to collect necessary data
- In a user evaluation the user assesses the product to list its good and bad qualities

These methods are useful for LPD since they contribute to ensure that the product is designed in a suitable way for the user by the possibility to evaluate during the whole development process. The evaluation can be reviews at the desk, tests in a lab or validations in the field, since there are different methods that are suitable to evaluate different aspects and different level of completeness. When products are evaluated from a user perspective, additional user needs may also be detected due to the existence of something they explicitly to relate to.

6 Discussion and Summary

Many of the ideas presented in this paper are already in practical use to varying degrees in companies applying LPD, but it is seldom stated that it is HFE that is used. The authors consider it important to make the connection between LPD and HFE visible and precise. This article highlights these connections and shows that there is an entire field of theory and methods that are ready to be used. Knowledge about the area of HFE makes it easier for more people to embrace the approach and apply it within their companies.

It is also interesting to see that LPD has a lot to contribute to the HFE-ambition to be a natural and integrated part in any product development process. Firstly, to show the benefits to study and clarify the user's needs and requirements and the value it creates for the user, "*Establish Customer-Defined Value to Separate Value-Added Activity form Waste*" [1]. Secondly to explain why it is necessary to invest large resources in the beginning of a development project (making it front loaded).,"*Front-Load the Product Development Process While There is Maximum Design Space to explore Alternative Solutions Thoroughly"* [1]. The third aspect is to state that being in contact with the users is an engineering work task and that it is important that engineers are involved from the beginning: "Gemba walk/Go and see"[3, 26].

This paper has presented the idea that Human Factors Engineering has a lot to offer as a supportive tool for Lean Product Development and an argumentation to support this. This potential contribution has also been identified by Budnick [27] who argues that ergonomists should have a leading role in lean enterprises. But since no evidence based research has been carried out and it is still a hypothesis, there is a great need to test this empirically. There are probably a large number of details that need to be investigated and solved for a successful integration of HFE and LPD in an organisation; hence much work remains to be done.

To summarize, in general we argue, from a theoretical perspective, that Human Factors Engineering has a great potential to support Lean Product Development in the work to avoid and reduce waste. This is achieved by developing products according to what the user wants and by making the user visible throughout the whole development processes. HFE can also help LPD by creating a development process that naturally becomes front loaded.

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