CREATING VALUE THROUGH LEAN PRODUCT DEVELOPMENT – APPLYING LEAN PRINCIPLES

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ABSTRACT
This conceptual article describes how companies can create value through applying Lean principles in product development. It provides input to a generic framework of Lean Product Development as it defines an explanatory model for effective knowledge enhancement and execution of development projects. The model consists of a two by two matrix given by a division of, at one hand, product development in two value streams, the Product Value Stream and the Knowledge Value Stream, and at the other hand in two phases, the Concept phase and Implementation phase. With this as basis it is discussed how four essential Lean principles, Flow, Continuous Improvement, Standardization and Visualization, could be applied. The difference in how the principles are applied in the matrix justifies the proposed generic framework.

Keywords: Lean Product Development, Toyota, Principles, Flow, Continuous Improvement, Standardization, Visualization

1 INTRODUCTION

The success of Toyota has lead to a widespread interest and thousands of companies around the world have implemented effective production systems applying methods similar to Toyota's. There is an increasing interest also in the Toyota product development system [1]. While Toyota's Production system, or Lean Production as it is generally denoted in the West, has been thoroughly researched, the principles and methods applied in Toyota's product development are less understood. The theoretical model of Lean Product Development is not so well defined and there is a need for further elaboration of this field.

In a holistic view Lean Product Development has three goals that apply in different areas. According to McManus [2] these are;

1. Making the right products, i.e. the creation of products that increase the value for all stakeholders.
2. Effective integration between product life cycle and the enterprise, i.e. applying lean product development to create value in the whole product life cycle and in the whole company.
3. Efficient product development processes, i.e. using the lean concept in order to eliminate waste, improve cycle time and quality in engineering.

In this article our intention is not to explain Toyota's product development system, but to contribute to a framework that is applicable for companies wanting to implement lean practices in their product development. We provide input to a basis for Lean Product Development through elaborating on an explanatory model presented in [3]. This model is further defined by discussing how some essential lean principles could be applied on practical level within product development.

The input to this article comes from multiple sources. We have carried out literature studies regarding general Toyota/Lean principles (e.g. [4], [5], [6]) as well as Toyota's Product Development System (e.g. [1], [7], [8], [9], [10], [11], [12], [13], [14], [15]). This is complemented with findings from action research during our industrial practice. The first author has experience from working several years with product development methodology at Toyota Material Handling Corp. The second author has acquired knowledge from numerous case studies and change implementations carried out in cooperation with a Japanese mentor with background at Toyota. The third author has a position within the truck company Scania to deploy lean, efficient and innovative methods in the product development department.

2 LEAN PRINCIPLES

Within Toyota's production and product development system some fundamental lean principles are found. In this article four of the most essential are focused on. These are:

- Flow. There is a focus on the flow where people deliver downstream at the right time, with the right quality. Everything that interrupts the flow must be eliminated through continuous improvements.
- Continuous improvements. A never-ending pursuit of perfect, efficient practices with all personnel involved through elimination of waste.
- Standardization. A solid baseline is a prerequisite for improvement of methods and tools.
- Visualization. Visual systems are used to expose deviations and disturbances, thus allowing quick countermeasures. It can also be used for visualizing processes and work-flows.

3 A LEAN PRODUCT DEVELOPMENT MODEL

In [3] an explanatory model for Lean Product Development was introduced. The basis of the model is two founding principles, depicted in Figure 1. These are:

1. In coherence with Ward [7] and the model developed by Kennedy [8] the objective of product development could be separated in the *Knowledge Value Stream*, where the objective is to capture knowledge and make it reusable, and the *Product Value Stream*, where new products are developed.
2. A division of product development into two different phases; the early *Concept Development* and the *Implementation* phase. While the concept development is a knowledge-oriented phase focusing on the creation of knowledge to close knowledge gaps and on minimizing project risks, the implementation phase is a more process-oriented phase. The focus of this phase is on the efficient execution of tasks in an environment characterized by lower risks and higher predictability.

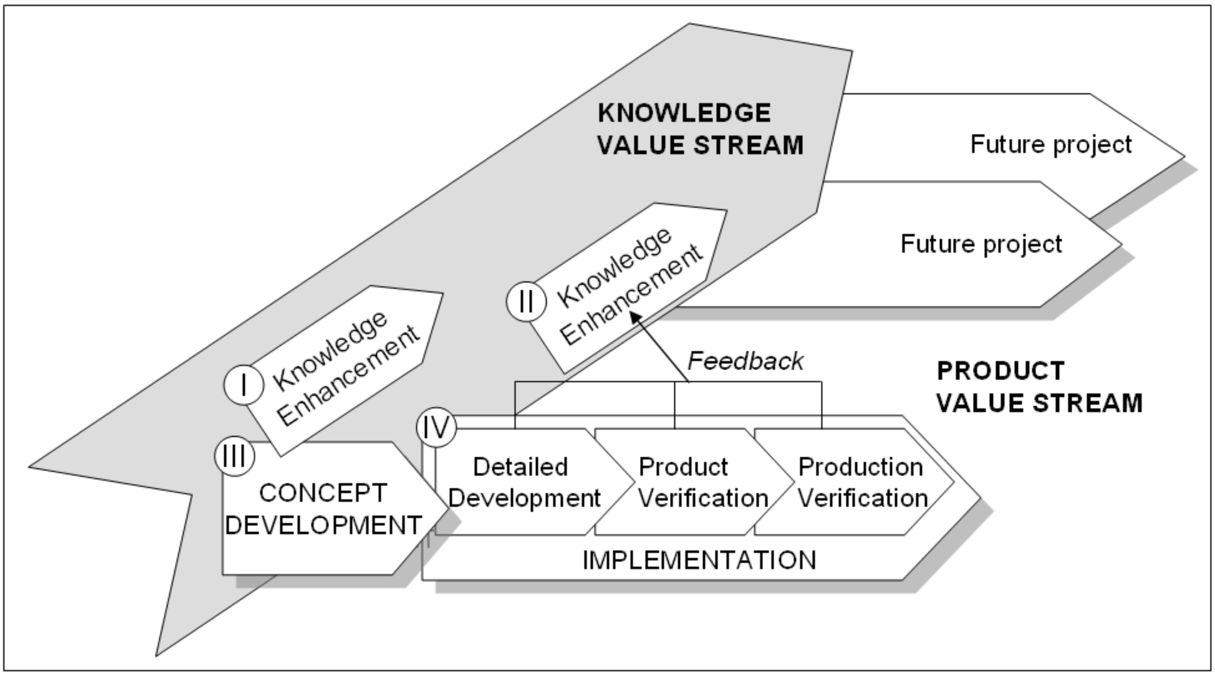

Figure 1. Two distinct value streams; the Knowledge Value Stream, which represents the organizational learning, and the Product Value Stream, which correspond to the target-focused development projects. This is combined with the split of product development into Concept Development and Implementation. Paragraphs 4.1-4.4 below refer to the Roman numerals (I-IV) in the figure. Figure from [3].

If combining the split in two value streams with the distinction of two main phases of product development a two by two matrix appears. This is shown in Figure 2 with the main issue that needs to be resolved defined in each quadrant.

	Concept phase	*Implementation phase*
Knowledge Value Stream	**I** How do we capture and reuse conceptual knowledge?	**II** How do we identify root causes and eliminate problems from re-occurring?
Product Value stream	**III** How do we identify and close all knowledge gaps upfront in a project?	**IV** How do we execute our projects efficiently?

Figure 2. An explanation model for Lean Product Development in the form of a matrix including the main issues that need to be resolved in each quadrant.

In Section 4.1 to 4.4 the above described model is further elaborated discussing how four essential principles of lean are applied; Focus on flow, Continuous improvement, Standardization and Visualization. These principles do not represent the full spectrum of all lean principles but to our experience these are significant in any Lean initiative. If more principles would have been included in the discussion in the article the result would have been scattered, fragmented and/or overlapping. A more complete overview of lean principles is found in Swan and Furuhjelm [3].

3.1 Quadrant I: Knowledge Value Stream / Concept Phase

The Knowledge Value Stream is about enhancing corporate knowledge to be generally applicable. In this quadrant of our model this is related to the Concept phase of engineering. Below the four lean principles we have chosen are elaborated on from an applied perspective.

Flow

Focus on flow in this quadrant of the matrix means focus on the flow of knowledge. This could be enhancement of the corporate knowledge in the fields of for example products and technology, but also customer’s preferences and manufacturing capabilities. Example of this is Technology Roadmaps broken down on sub-system level that set the direction of a knowledge flow.

Within Toyota the Line managers on a subsystem level are responsible for the knowledge flow and thus ensuring continuous learning. Pull flow of knowledge can be created through requesting and through regular reviews of new A3’s, Integrating Events/Knowledge Reviews, and updated standards, methods and tools.

Continuous Improvement

Continuous improvement in this quadrant means a never-ending advancement in how the company captures and makes knowledge reusable related to the conceptual level of development. This includes a constant evaluation of the methods for acquiring knowledge, the form of documentation and spreading this in the organization.

The improvements include both process and structure. Process improvements can be for example improved ways of performing testing of different concepts and sub-systems to ensure maximum learning. Structure improvements can be an improved knowledge documentation structure, for example a more suitable electronic library with efficient search engines.

With an efficient process and structure in place the company has a baseline for filling the Knowledge Value Stream with know-how in the form of for example trade-off curves with dependencies between customer interests and Design parameters.

Standardization

Standardization in Quadrant (I) means setting up a structure for capturing and making knowledge reusable that is the same all over the company. For acquiring knowledge this could be for example determining testing methods to ensure that knowledge is generated not only on project specific level but guarantees to be applicable also in other projects. More specifically test-to-failure provides more general knowledge than tests carried out only till the point where it has been proven that the particular product specification has been met.

For making the knowledge reusable companies could have standardized methods in terms of ways of documenting and storing knowledge. For example this could be a standardized format for test reports, trade-off curves, A3 document system, and guidelines and checklists. There could also be standard ways of presenting information for example in user-driven Wiki solutions. Furthermore companies could set up formal systems for mentoring new employees to gain knowledge in corporate practices.

Visualization

In the Knowledge Value Stream visualization is a key principle in order to be able to spread the existing knowledge in the organization. The visualization is then a technique to make corporate learning more efficient. Both the product and the process dimension can be visualized. The new knowledge can be stored in different ways. The reports or other documents could preferably have photos documenting cases of for example quality issues or roadmaps. Another example are design guidelines on a sub-system or component level with sketches and drawings showing good and bad examples of different designs.

3.2 Quadrant II: Knowledge value stream / Implementation phase

While Quadrant (I) relates to the conceptual phase, this regards the later phases of the projects with a more high-speed, repetitive engineering with for example release of drawings. The Knowledge Value stream, i.e. the enhancement of the corporate knowledge, relates here to capture and making reusable feed-back and learning from the projects, see Figure 1.

Flow

Focus on flow means in this quadrant focusing on the flow of improvements in methodology. Root causes of deviations are identified and eliminated through changed and improved ways of working, i.e. process standard. Pull flow can be created through requesting and reviewing the flow of improvements in the system. The improvements made will lead to a smooth and efficient flow of project tasks. For example, flow can be improved by weekly status meetings at a Kaizen board where small improvement tasks are pulled forward each week.

The feed-back itself from IV to II is a flow of information that needs to be taken care of and evaluated continuously during the project and not only as lessons learned after ending the project. The information shall be available when it is needed. This flow can be product oriented with information from development projects to pre-development projects. This in order for the new knowledge to be used in future products. It can also be process oriented focusing on improved ways of working. This can be achieved through for example check sheets or design for manufacturing guidelines that are fed back to the Knowledge Value Stream to be applied in future projects.

Continuous Improvement

Continuous improvement is a highly relevant principle in Quadrant (II). The company takes knowledge about optimal methodology derived in the Product Value Stream and transforms it to generally applicable knowledge in the Knowledge Value Stream. The intention must be that mistakes made in one project should be avoided in the following ones. Furthermore improvements made in terms of efficiency should be continuously applied throughout the company.

There are several things to accomplish in order to reach continuous improvement. There must be a mind-set in the organization where the importance of continuous improvements is a fundamental element. In the projects lessons learned sessions could be an efficient tool for extracting learnings. The knowledge could add to the Knowledge Value Stream in two different ways. Either it is documented and from the documentation future projects can extract experiences and apply these. Or the knowledge is spread orally. This could be done in many ways. For example key findings from the lessons learned are presented afterwards to a wider group or project managers of similar projects.

Standardization

Applying the lean principle of Standardization in Quadrant (II) means that the company has a standardized way of capturing knowledge from the projects and making this re-usable. This could be for example a structured way of ensuring a continuous update of guidelines/checklists and standards. This could be regarding process related matters as well as other learnings in projects. A standardized way of performing lessons learned sessions, for example defining when in the projects, which participants, methodology during the sessions etc is an application of the lean principle standardization.

Visualization

An example of this principle on applied level is a Continuous Improvement board on the wall, to visualize the flow and status of improvements in the team. Another example is Value Stream Mapping. This is done through a “walk-through” of the entire process from beginning to end, usually carried out as a workshop. The demands of the internal and external customers are first identified. The flow of material and information is then mapped, identifying each process time and lead time. Through visualization the process is easy to understand and can be communicated in the organization.

Information related to the product can be visualized with updated trade-off curves or product related performance charts in order to be available for the next development cycle.

3.3 Quadrant III: Product Value Stream / Concept Phase

In the Product Value Steam the products are developed and brought to the market. This paragraph elaborates on how the four lean principles are applied within the Concept Phase. It is related to McManus [2] first principle where the focus of lean should be on making the right products.

Flow

Here flow means the focus on flow of required project specific knowledge in order to close the knowledge gaps in the early phases of the project. Flow in the upstream phase of the project can be created by a number of means:

- Clear targets and vision of expected result, thus setting the direction.
- A common understanding of the challenges and knowledge gaps on sub-system level.
- The focused work on closing the knowledge gaps through modeling, simulation and model testing to verify concept performance on sub-system level.

Pull flow can be created through regularly paced integrating events, where complete learning cycles (PDCA) are expected to be completed and presented visually (A3’s).

Continuous Improvement

In this quadrant the principal of Continuous Improvement could be applied in a similar way as in Quadrant (I) but more related to the early phases of the development projects. Improvements are related to the issue how a company better can identify and close all knowledge gaps upfront in the project. This could be for example implementing frontloading in terms of moving prototype testing from physical prototypes to digital mock-ups. Another example is putting into practice better ways of performing concept evaluations and early integration testing where different sub-systems are tested together.

Standardization

Applying the lean principle of Standardization in Quadrant (III) means ensuring that the company standards are followed in the early phases of the product development. Relevant standards in this respect could regard how early testing or concept selection should be carried out. In wider terms the company could have standardized practices for problem solving for example by use of A3-technices.

Visualisation

Early in the project there is a need of making gaps and challenges in the project knowledge visible. On whiteboards major risks could be posted to ensure a high degree of attention. The risks and challenges could then be transformed to migration activities within the project.

Another thing that can be visualized is product related information such as functions and architecture. Within engineering design there are several methods that support visualization of product related issues. One of these methods is Function/Mean-tree.

3.4 Quadrant IV: Product Value Stream / Implementation phase

This quadrant is the most intense in terms of resource allocation in many companies. The more detailed design work is carried out and the product is industrialized. The high intensity naturally means that the benefits of lean initiatives giving improved efficiency are high. This quadrant is related to McManus [2] third principle as defined in the Introduction of this article.

Flow

This means a focus on the efficient execution of tasks in order to complete the project in an efficient way with few or no loop-backs. There are several success factors how this can be accomplished:

- A well established standard process, covering best practice as defined from experience of many past projects.
- Responsibility based planning, often referred to as Visual Planning, on the detailed level, i.e. a plan where the engineer has been involved and feel committed to the plan. This should be broken down on individual and daily work packages.
- Frequent status reviews to identify and act on deviations and risks.
- Small batches of work and gradual handovers to the next link in the chain to minimize queue time.
- Agreement with your internal customers on the deliverable, including content and deadline. And an insurance that they are prepared to receive the delivery without queue time.
- Balanced workload where planned total workload is well below available capacity (for example 80%) in order to maintain the ability to act on deviations and issues without threatening the plan.

Continuous Improvement

In this quadrant, applying the principle of Continuous Improvement means endless refinement of the ways to work within the projects. This could be at any level of the project execution, including improving the ways the project is managed, speed up communication, make the engineering work or final testing more efficient.

The principle of Continuous Improvement is more relevant within large projects. This is because some changes in methodological practices could take time to accomplish. It could also imply the need of significant resources to implement the change and generally only large projects have these available.

Standardization

Standardization is a highly relevant principle in this Quadrant (IV). Standards are needed as a baseline for continuous improvement. There are different levels of standardizations both related to the product and the engineering methodologies. From a product perspective three levels could be identified:
- A company external level, regulated by legislation and branch organizations. This could be for example norms and regulations regarding emissions and safety.
- A company standard in terms of a process description with tollgates etc defining general, mandatory milestones. This could also define which and how design reviews are carried and how drawings are released. Another example is the test-ordering process
- The lowest level is on a domain-level. The way different engineering activities are performed are standardized and described in documents found in the company management system.

Visualization

Visualization in the project phase focus on showing the status of the project. There are different techniques for this. Some companies have what they call a pulse-room. In this room the status of the project or projects can be highlighted or displayed with different types of visual markers on a wall or whiteboard. The progress of a project can be highlighted according to a traffic light principle.

Another interesting visualization of projects is an Obeya, means large room in Japanese, or “war rooms” where information regarding one project is on display. In these rooms relevant information regarding a specific project can be found often in a visual way. Typically deviations and major risks are displayed as well as project plans.

4 CONCLUSIONS

In this article we try to contribute to a framework for Lean Product Development that could function as a basis for lean initiatives within product development. Building on the framework introduced in Swan and Furuhjelm [3], four essential lean principles and presented. For each of these it is discussed how they could be applied in the different areas of product development.

The basis of the discussion is a four field explanatory model of Lean Product Development. This is further defined in [3]. Briefly, our model adds to Kennedy's model [8], which defines product development in two main flows; the Knowledge Value Flow and the Product Value Flow, a split of product development into two phases with different characteristics. Firstly, the Concept phase, which is a knowledge-oriented phase focusing on the creation of knowledge to close knowledge gaps and minimize project risks. Secondly, the Implementation phase which is a process-oriented phase with focus on the efficient execution of tasks. The model accordingly comes in form of a two by two matrix where different characteristics of the tasks performed in each element can be distinguished.

	Concept phase	*Implementation phase*
Knowledge Value Stream	Systematic knowledge creation and generalization for reuse in future projects.	Systematic problem solving to identify root causes to learn as well as to standardize into methods that prevent problems from reoccurring.
Product Value Stream	Identification and closure of project-specific knowledge gaps.	Efficient flow of engineering tasks with few interruptions since risks have been reduced in the Concept phase.

The essential Lean principles that are focused on in this article are Flow, Continuous Improvement, Standardization and Visualization. We connect each principle to the quadrants as defined in the matrix. For each quadrant examples are given how the principle could be applied.

We mean that the all principles are relevant to some extent in each of the quadrants. But it is important to note that they are applied differently in each quadrant. The model with the application of the principles could, according to our experience, be useful when identifying a strategy for a company wanting to implement lean within their product development. A natural outcome from this strategy is a definition of the way forward and a commitment for the implementation in the organization.

Since this paper does not handle all principles within a Lean approach a natural next step could be to discuss and interconnect other principles in the same way as we have done in this paper.

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