Improving the System Architecting Process through the Use of Lean Tools

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Abstract--**The impact of embedded systems within the automotive industry has grown very rapidly and is today influencing most part of the product development process. This technological change puts high demands on the development process in order for the company to stay competitive.**

The architecting process is performed during the early phases of the development process when uncertainty is very high. The architecting process will not create immediate value to the end customer, but rather create the architecture on which value in terms of product features can be developed. The architecture will enable value creation when working properly or, in the worst case, prevent value creation.

Lean is a product development philosophy that aims at creating value for the end customer. A Lean tool used to improve the value creation within a process is Value Stream Mapping (VSM). VSM has in this work been adapted and evaluated to analyze and identify improvements of the architecting process within embedded systems development. In this paper we present practical experiences from using this adapted VSM. The evaluation was conducted through interviews at two automotive manufacturers. VSM is shown to be a valuable tool to identify waste and thereby improve the architecting process.

I. INTRODUCTION

The product development process is often depicted as a straight forward process starting with an idea and ending with a validated product. The reality is often not as stringent [3], and iterations and rework is part of most product development processes. There are methods such as real options [4] available to evaluate different technical design decisions. To make the right technical decisions is very important, but to stay competitive this most be done in the right way. According to Ward [20], 60% of the time invested within product development is waste.

To stay competitive in the automotive industry vehicle manufacturers are forced to release new models more often. At the same time the product portfolio must be further diversified in order to satisfy individual customer demands. The shorter development cycle and increased number of concurrent models brings an increased need for transfer of design knowledge. In this study a car manufacturer (Volvo Cars) is compared with a manufacture of commercial vehicles (Scania). A commercial vehicle must manage to run 300 000 km per year and breakdowns do not just influence the driver, but also the delivery time of the goods it carries. Commercial vehicles have a lot in common with passenger cars, much of the functionality are found in both segments. The passenger car industry has traditionally been adopting new technology earlier. This can be explained by the different needs of the customer.

Today most innovations made within the automotive domain are driven by electronics. Future functions that enable vehicles to communicate with not just other vehicles, but also the infrastructure [2]. Those future demands are increasing the complexity and the boundaries of the automotive electronic and electrical (E/E) system. The architecture of the E/E system has a large impact on how expensive or difficult those changes will be to implement. The architecture will enable value creation when working properly or, in the worst case, prevent value creation. The process of architecting the E/E system is therefore an important process to improve.

In our work, architecting is viewed as the process of shaping the architecture to meet customer demand by balancing requirements, guiding principles and product vision. As we see the architecting process is central to and dependent on many factors within the organization. In order to improve the process the involved activities would need examining. With this in mind the following research question is studied in this paper:

A. How can the system architecting process be mapped in order to identify improvements?

A hypothesis to be tested is whether VSM is a suitable method.

The literature review explains the concept of lean and how it relates to system architecting. VSM is then reviewed in Section III followed by a description of the adapted method for performing VSM on the system architecting process. This method is then utilized on a case study described in Section V. The results of the case study are then discussed followed by a presentation of future work to be done.

II. METHOD AND METHODOLOGY

The literature on Lean and Value Stream Mapping (VSM) has been studied to understand the concepts. This knowledge has been used in the process of defining the case study. After the case study was constructed, it was tested on one person at each company who previously has been employed as system architect. The chosen format of the interview was semi-structured and the answers were recorded by a person with deep knowledge of the architecting process. A semi-structured interview has predetermined questions, but the order can be modified based upon the interviewer's perception of what seems most appropriate. Question wording can be changed and explanations given [15]. The interviews at both companies followed the same template and the answers given were then used to describe the process.

III. LITERATURE REVIEW

A. Lean

Lean is a practice that considers the usage of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer, who consumes a product or service, value is defined as any action or process that an internal or external customer would be willing to pay for. The concept of Lean production was defined in the literature by Womack et al. [21], but derives from the working methods developed by Toyota in the 1950s.

Lean methods focus on increasing customer value and on the people who add value. A Lean-based company encourages its employees to perform continuous improvement and to learn. This is done by cross-functional and parallel work and a high degree of standardization in order to optimize across organizations. The concept of Lean production has today moved from manufacturing into various sectors, such as maintenance, purchasing, logistics, and to product development which is the topic of this paper. Lean production is achieved by careful planning of a production line in order to optimize the production flow to meet customer needs. Each assembly station is arranged to minimize unnecessary motion and transportation of material. Each assembly station is assigned defined tasks to be finalized on a specific time in order to achieve a balanced flow throughout the production-line. A balanced flow means that the results are delivered on-time without waiting or over-production.

An important starting point of lean product development is to view the product development as a process, and like any other process there are repeated cycles of activity [10]. This is important even though the resulting artifact is per se novel to some degree. From a process perspective, there are many activities that are shared between different development projects. By eliminating the waste in a process, an increased flow is achieved, thus new products can be brought to the market at a higher pace.

There are two main differences between manufacturing and the early phases of product development. The flow does not consist of materials but more often information and knowledge in different shapes. Different organizational and geographical locations of the stakeholders influence how this knowledge is shared. The process does not consist of one flow, but instead iterations are often made and different concepts are developed in parallel.

Allen Ward [20] claims that 20% of the time spent in product development is value adding time. Nonvalue-creating time such as administration work occupies 20% and the remaining time is waste. This fact would suggest that optimization is possible if we identify the wasteful activities. It is common to define seven types of waste [10] and value stream mapping is one method to identify the waste within system architecting. According to Allen Ward [20] the most frequent waste in development is waste of knowledge. He divides knowledge waste in three categories: scatter, hand-off, and wishful thinking. Scatter is described as actions that disrupt the flow of knowledge. This disruption can be due to communication barriers and the use of inappropriate tools. Example of knowledge waste created by hand-offs is to move people around rather than assigning them from the beginning to the end. Waste due to wishful thinking is for instance to test according to specification rather than to test to learn about the limits of the product.

In the literature, there is little work on how Lean can be applied to the process of developing software-intensive systems. Poppendieck and Poppendieck [13] present how Lean can be applied to the software development process. In their work, typical wastes to be found are hand-offs between individuals, switching between tasks and adding extra features. Value Stream Mapping is presented as one way to find waste.

IV. VALUE STREAM MAPPING

There are many different techniques available for process modeling, but Value Stream Mapping (VSM) differentiates in focusing on value creation. Value Stream Mapping (VSM) was initially a tool for improving the manufacturing process [16] and has shown to be effective within manufacturing [7]. The method is today also used within many other disciplines. The process includes four steps which are described in the next sections.

A. Value Stream Scope

The purpose of scoping is to determine what process (value stream) is to be improved and to create a common view of the process to be analyzed. This means understanding what processes are included and where the process starts and ends. It should also be decided upon who will perform the VSM and who will support the event, including management. The output of the scoping is therefore an input-output view (Fig. 1) of the process and its control parameters, but also a working plan [5]. Control parameters could be a common strategy or business goals. Enablers are resources consumed by the process such as available people and tools.

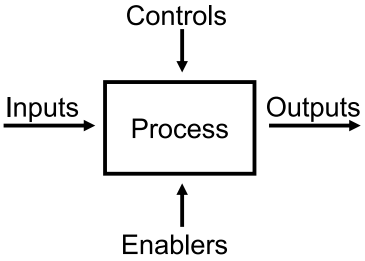

Figure 1. A input-output view of a process

B. Current State

The aim of this step is to understand how things currently operate. This is done through a walk-through of the entire process from beginning to end, usually in a workshop manner. The demands of the internal and external customers must be identified. The flow of material and information is then mapped, identifying each process time and lead time.

To illustrate how this is done, a fictive example is presented in Fig. 2. The sub process of updating a communication interface in a document and a database is mapped with the recommended symbols [8]. Figures of the process are given through a walkthrough of the process. The process time is the required time it takes to complete a specific task when working without interrupts. The task of creating an interface description takes 120 minutes from start to finish. The number of people and resources normally available for a task are given after the symbol in the middle. In this example, we find out that the dedicated employees normally have 30% time available for creating interface description.

It then normally takes half a day from the handover until the work to update the database is started, which is indicated below in the IN process box. The task to update the interface database is then started, taking an average of 30 minutes to perform with one person available at 50%.

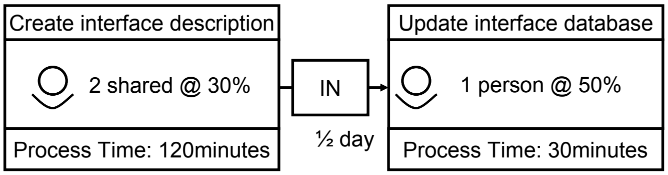

Figure 2. The subprocess of updating a communication interface in a document and a database.

C. Future State

The purpose of this step is to improve the process, i.e., to design a lean flow. This is done by analyzing the process with regards to the Lean principles. There are a number of questions that can be asked to find those improvements [8]. What does the customer really want? Which steps create value and which steps are waste? How can we design a flow of work with fewer interruptions? Using this set of question some additional issues will arise in our example: Are the interface description what the customer really wants or are some parts not necessary (e.g. waste)? Does the information need to be added to two different sources or would the database be enough? Can the task be done by the same person and thereby reduce the lead time?

With the guidance of those questions a future state of the example can be drawn. If the document is not needed and the task can be done by the same person the following future state can be drawn. The lead time is reduced by half a day and the process time with 30 minutes (Fig. 3).

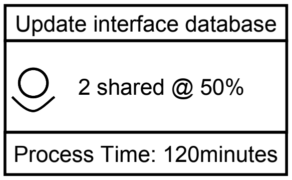

Figure 3. The result of the future state

D. Work plan and implementation

This last task is the final goal of the VSM, namely to ensure that the improvements are implemented. It is done by describing the specific improvements that are chosen to be implemented from the previous step. A work plan is made showing what will be done by whom at what time. The work plan is used to follow-up that the tasks are being performed. The planned changes must be communicated to everybody involved in the process. To make the necessary changes it is crucial to have management attention. Summarizing what is learned in the VSM event is done in order to ensure that knowledge is carried to the next time (lessons learned).

V. VSM FOR SYSTEM ARCHITECTING

In this section we will present an adapted VSM for a system architecting process of a software intensive system. The purpose of creating an adapted VSM is to enable comparison between different organizations and thereby improve knowledge transfer. In order to make this adaptation, a literature review of the architecting process has been carried out. The authors' previous practical experiences as system architects has also aided the work.

A. Value Stream Scope

The architecting processes is influenced by many different factors [18]. To be able to understand different architecting processes one must first understand the surrounding circumstances. The attributes that are important to gather in order to understand the context were derived from the literature [1, 9, 14]. The attributes in table1 are derived to make a comparison possible of the architecting process and grouped according to the BAPO-model [18].

When those attributes are known and understood a comparison can be made and the right conclusions can be drawn. The architecting process (Fig. 4) starts when a change request reaches the architecting team and ends when a solution is presented and decided upon. The input of a legacy architecture and customer requirements are transformed into a revised architecture, which adds customer value and knowledge to the organization. The process is controlled by business attributes and enabled by the organizational attributes. A generic input-output view of the system architecting process can be seen in Fig. 4. When the attributes are known the value stream scope is also clearly defined. In our case study, figures about the different companies were gathered from financial reports and through a company contact. Less exact attributes such as "balance of power" were obtained after analyzing the interview data.

TABLE 1 ATTRIBUTES DESCRIBING THE CONTEXT OF THE SYSTEM ARCHITECTING PROCESS, WITH EXAMPLES GIVEN IN PARENTHESIS.

Business Number of products produced per year Number of product variants Procurement strategy (make or buy) Lifetime of the system in number of years	**Architecture** Level of SW/HW architecture Type of architecture (product-line, single product) Principles or architectural rules Architectural lifecycle (continuous, revolutionary) Number of parallel architectures
Process Development process (Stage-gate) R&D Organization (national, one location) Guiding principles Culture (consensus) Methods in use	**Organization** Geographical distribution of the R&D organization Number of employees in the R&D organization Number of employees of the system development organization Type of organization (matrix, project) Balance of power (line, project) Organizational location of architects (co-located, separated) Number of system architects Architectural power (line, project, architects)

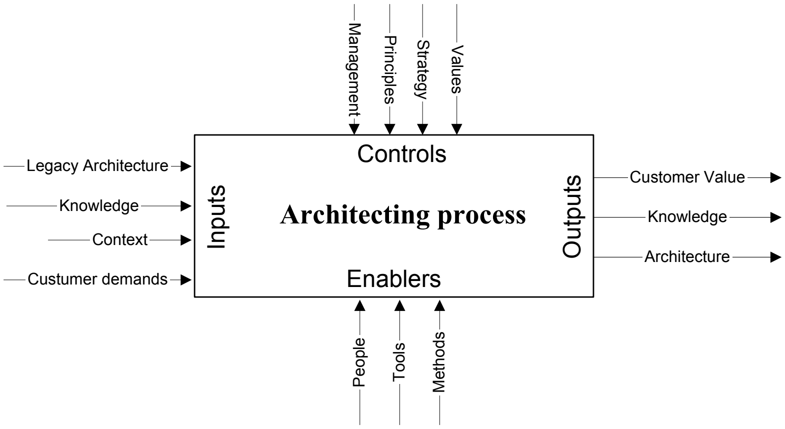

Figure 4 The attributes affecting the architecting process

B. Current State Drawing

Depending on the process maturity of the organization, estimations of lead and process time will be hard to find, but might be interesting in a second VSM iteration. Therefore a first VSM is chosen to be made lightweight. The architecting process is a support process that usually aids an overall development process. The current state was obtained through semi-structured interviews at two companies. Through the answers to the interview questions the system architecting process of the two organizations were analyzed. The differences in the two organizations ways of working were then mapped to a reference process (Fig. 5) derived from the best practice according to the literature [6, 9, 11, 14]. Waste and deviations from the reference process were then documented. Available performance measurements such as throughput, customer satisfaction or first pass yield were also taken into account. The output of this step is an image of the created value stream map.

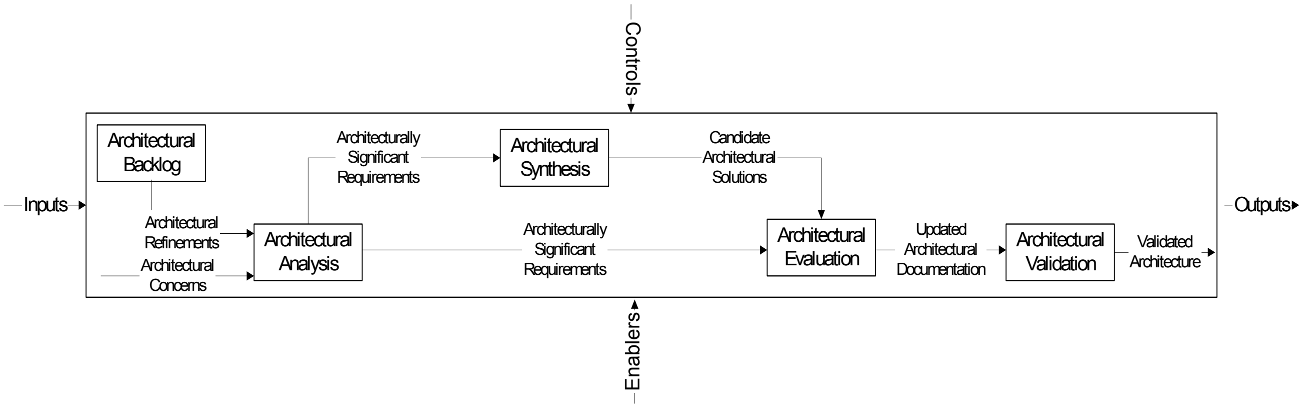

Figure 5 Reference architecting process

A special difficulty when analyzing the system architecting process is that much of the value created, and waste removed, is actually seen in other subprocesses of the product development process. The architecture organizes the work of many activities, and a good architecture provides clear and simple interfaces between subsystems, making the system development for these parts more efficient. Finding the best balance between the amount of architecting vs. system development is one of the most difficult parts in product development management.

C. Future State Drawing

Most of the customers of the architecting process are internal and the customer value is difficult to calculate. The questions applied in a traditional VSM (section IV) might therefore be hard to answer but will none the less be important. To make the results comparable the different categories of waste found should be documented. The architecting process is supportive and inputs are given at various times, which make rework hard to avoid. Waiting until all inputs are available could stall the overall development process. The difficult task in this step is therefore how to cope with this uncertainty and maximize the value creating activities.

The future state of the process is achieved in two steps. The first is to find countermeasures to remove non-value-adding activities found in previous step. Those can be as simple as to stop producing a document that is not used, but in most cases it will be more complicated i.e. changing the way architects interact with other stakeholders. The second step is to benchmark the current state, in our case the other company. For future users of the method the two case-companies documented in this paper can be used as comparison. The output of this step is an improved process.

D. Work plan and implementation

A work plan is made showing what improvements could be done. To ensure success of the work the suggested improvements should be prioritized. It is important not to overload the organization with changes. Improvements leading to fast return on invested time are a way to encourage further work on improvements.

VI. CASE STUDY

The case study was conducted at two different automotive OEMs using semi structured interviews. In the study the researchers interviewed all architects available and willing to participate, which resulted in more than half of the persons working as architects at each company were interviewed, 4 at Scania and 5 at Volvo Cars. In addition to this the managers for the architecting group were interviewed at both companies, totalling the number of interviews to 11. Of the 11 respondents 2 were women. The interview started with some introductory questions to get some background about the respondent followed by a set of predefined questions. To ensure participation the length of the interview were kept to one hour.

A. Scope

The two companies are similar in both being automotive OEMs in the premium segment and both being located in Sweden, but different in aspects concerning organization, business and architecture. A clear difference is the types of products being produced, cars and commercial vehicles.

The main differences in business attributes are the production volume and procurement strategy. Volvo Cars buys a much larger part of the EE system and is also producing a much higher number of vehicles per year. Even if both cost and quality are important for both companies, Volvo Cars has a stronger focus on cost and quality is found more important at Scania.

Scania has chosen to have one common architecture which is continuous evolving and Volvo Cars has several parallel architectures. The two matrix organizations are very similar in size and their R&D department is both located in one single location. The biggest difference is found in the balance of power between the line and project. At Volvo Cars the main power is in the project organization and at Scania the line organization has the main power.

The process is managed differently, Volvo Cars uses traditional methods for communication and process follow-up and Scania uses visual planning and Obeya rooms [10]. An Obeya room is a place where cross functional knowledge is visualized and is used to show progress and to get a overall view. Respondents at both companies think that the decision making is slow. The architects at Volvo Cars and Scania have similar experience within the field, but the architects at Volvo Cars have been within the company significantly longer.

The inputs to the process were different in how changes affecting the architecture were entering the process. Scania has a well defined process into which all changes are entered. Volvo Cars has a similar process, but the process is not as settled and changes are therefore sometimes stumbled upon.

B. Current state

Both companies mapped easily to the reference process, with one exception. No formal evaluation step was made; evaluation was only mentioned to be made in rare cases. It is important to note that the process is not as sequential as it might appear in Fig. 5, iterations are made between all steps and especially between the analysis and the synthesis. Those iterations lead to waste in terms of waiting for information, which delays the process in both companies.

The tools used for documenting the architecture at Scania are not integrated which leads to waste when the same information needs to be entered more than once. Definitions of important concepts such as architecture are not defined at Scania, and this is waste caused by a communication barrier. The shorter employment time of the architects at Scania could also cause waste because of lack of company knowledge. The architects at Volvo Cars are assigned to a single architecture and knowledge sharing between them is therefore limited.

C. Future state

The decision making process in Sweden is known to be based on consensus decisions which leads to more meetings and communication [12] than areas with other culture. More meetings are not necessarily waste as long as knowledge is shared and the right people are attending well prepared meetings. It is important though to ensure the meetings to be effective. The frequent iterations are often due to loss of information in previous development steps. This waste could probably be eliminated through improved knowledge transfer of design rationale. Both Volvo Cars and Scania could document design rationale using the A3-technique [17]. A3 is a practical knowledge sharing mechanism using one single page to report e.g. decision-making or problem-solving.

A comparison between the two companies shows that there are a number of value-adding methods that could be borrowed. Scania is today using workshops as a method during the synthesis, and this could be one way to improve knowledge sharing at Volvo Cars. A similar tool chain as the one used at Volvo Cars could eliminate the waste caused by multiple entries of data at Scania. Scania uses visual planning [10] to keep track of the progression of tasks and workload of the architects, and this could improve how the backlog is handled at Volvo Cars. Working in pairs and in different areas increases knowledge sharing at Scania, this could also be tested at Volvo Cars. This type of knowledge sharing also provides a more flexible staff that can help out and reduce workload of other architects. Common understanding of different important concepts in the architecture should be improved at Scania to make the knowledge sharing more effective. Design reviews are made regularly at both companies and provide value as a knowledge sharing activity. Scania also uses feedback from the test department to validate the architecture; this can be improved at Volvo Cars.

D. Work plan and implementation

The suggested work plan was to first of all present the result for the two companies and to let them prioritize the suggested improvements. As this case study was made on a real process with real people it will take some time before a possible change take place. This is therefore not included in this work.

VII. DISCUSSION AND FUTURE WORK

In this paper the theory of Lean and VSM has been explained and a adapted VSM has been presented. The adapted VSM was then tested on a case study through 11 interviews at two different companies. The result of the case study has been presented at the two companies, who found them interesting, but most of all inspiring for their future process improvement. The indicator best showing that the mapping was valuable to the companies is that the presentation was asked to be held twice.

During the interviews it was important to ask and understand the previous experience of the respondents. Depending on their background respondents will have different perspectives. The answers of the respondents at each company were surprisingly similar. The author’s knowledge of the field was found important to make the interviews effective and to understand the acronyms and technical terms used. Improvements before a future case study will be to reduce the number of questions in the interview template that were found redundant.

In future work the interviews will be further explained and the case study expanded to include more companies. This will provide academia with knowledge of how architecting is performed. The industry can use the methods found for comparison and inspiration of process improvements.

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