

SUPPORTING REQUIREMENTS MANAGEMENT IN EMBEDDED SYSTEMS DEVELOPMENT IN A LEAN-INFLUENCED ORGANIZATION

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1. Introduction

Mechatronic products such as modern cars are rapidly moving into having more functions realized by electronics and software. There are unique problems with embedded systems development (mechatronic design) and the ability of IT tools and systems to support the specific needs (Bergsjö, Vielhaber et al. 2007). The increased amount of information available, and the need to manage this information from several and traditionally different engineering fields, have made it evident that it is no longer possible to design without solid knowledge about what is going on in related fields. With a different set of development tools, vocabulary and process traditions (Nambisan and Wilemon 2000), the mechatronic field now has to confront the design tasks as an integrated design team.

Related research has been undertaken mainly in formalized organisations such as the defence industry (Sutinen 2004). IT architecture and legacy need to be investigated when introducing new IT support tools (Stark 2005). In the mechatronic field, architectural issues are even more difficult since IT support systems have been lagging when it comes to supporting several technology domains. This is because they have focused upon a specific information management issue within e.g. mechanical engineering (Burr, Vielhaber et al. 2005). Product data management (PDM) systems and requirement management (RM) tools have been utilized to bridge these types of problems e.g. (Malmqvist 2001). Specifically, IT tools for the early phases of product development, such as RM tools, present difficulties since requirements often are specified in the beginning of a development process and are modified later (Engwall 2003). The IT tools also have a problem with managing a flow that is characterized by iterations.

Both organizational and product changes are required when the electrical and software content of a product grows. The way the product is modelled needs to be updated as well as the means for how the product and the process are documented. Performing these changes is not an easy task, and the designer may or may not understand the underlying reasons for implementing IT support systems. It is thus important that designers are motivated by the chosen approach (Bergsjö and Malvius 2008).

This paper aims at increasing the knowledge regarding prerequisites for supporting mechatronic engineering. The study has focused on assessing the company culture and legacy in order to establish the need and benefit of increased formalization.

2. Methodology

2.1. Case Company

The study has been conducted at Scania CV in Embedded Systems Development. This is the unit that develops electronic functions and systems for the complete Scania trucks and buses (Figure 1). The study was performed with a focus on systems architecture and support for requirements engineering.

2.2. Studies

The pre-study for the research presented in this paper was performed during 2007-2008 and focused on the mapping of three historical development projects at Scania. The pre-study contained several interviews and meetings in order to map the studied processes, and the pre-study is documented in a master thesis (Larsson 2008).

As the main part of this research work, two parallel studies have been conducted: a questionnaire-based study and a qualitative study. They are named Business Study 1 and 2 (Figure 2). The questionnaire was handed out together with the qualitative interview, and contained suggestions that were graded on a scale 1-10 by the interviewees, marking the degree to which they agreed with each suggestion. The qualitative interview followed an interview guide with approximately 10 areas where open questions were posed. All 10 interviewees came from the manager and technical expert roles. Interviewees belonged either to the Embedded Systems department or to a project/product planning support organization. Managers from every level of the Embedded Systems department were interviewed as well as technical and senior technical experts. Two additional interviews were performed with experts from the IT department. The average interviewee had 10+ years of experience in the business, most of that time at Scania CV. The interviews lasted for about two hours each. The main research questions for this study were:

- What support for requirements management would be beneficial, regarding requirements management, within Scania CV embedded systems development?
- What could be a suitable degree of formalization in this context?

In a parallel study, a demonstrator for management of requirements was implemented in a PDM system. This demonstrator is not covered within this paper.



Figure 1. Scania Products

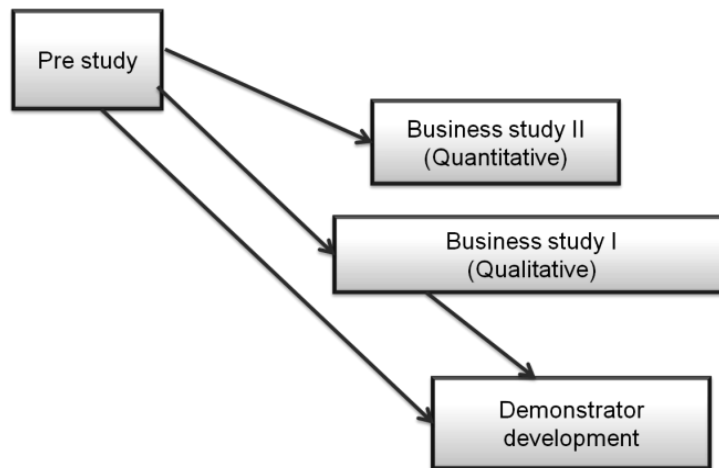


Figure 2. Study setup

3. Findings and Analysis

Scania CV is a large organization with relatively informal methods for requirements management and management of product properties. The company culture is highly influenced by Japanese development traditions where experience, product knowledge and the individual engineers are highly respected. This philosophy has its roots far down in Scania's history and has been highlighted during times of change and quality problems in the past. The quality problems that arose as an effect of the launch of a new product platform about a decade ago led to a great focus on Japanese-inspired quality work, which has gradually improved the product into one of the best on the market regarding uptime and other important product properties for trucks and buses. Other initiatives were taken when Scania was the subject of a hostile takeover, and the "Scania culture" was threatened and needed to be further defined and secured. This was the time when important Scania properties were defined that should give the company and the product distinct means to separate it from the competition.

During the latest years there has been a large expansion of Scania's production and also innovation when it comes to new product features, especially within embedded systems development. However, the expansion has had the result that some parts of the development process and requirements management, including requirements engineering, and test procedures need to be better managed in order to ensure the quality of the product in every step. There is also a greater need to document product solutions in a way that can be easily traced and understood by future Scania co-workers. When improving a product it has been difficult for the involved engineers to find information related to why a specific solution was chosen and the motivations behind the different concepts. In order to better manage this in the future, ways of documenting and tracing relevant information quickly need to be developed. One particular reason behind these difficulties is that there are more people working with embedded systems and software functions, which means that it is difficult to know everything or at least to know the person with the knowledge; this is especially true when a knowledgeable person is retired and leaves the company. This study tries to identify these new formalization needs in order to make them a part of a future development process while maintaining the lean informal development methodology. When the work procedure has been formalized, improvement work of the formalized processes can be initiated. This was expressed by one of the interviewees:

*"Routine work should be standardized in order to do the same thing every time.
After that we can work with continuous improvement of that work procedure."*

3.1 Mechatronic Product Development at Scania

The product development regarding embedded systems is organized around two main departments, the vehicle electronics department and the engine electronics department. The focus on engine performance as one of the most important aspects of a Scania product has led to this division of departments. There is also a historical reason: previously all electrical departments were distributed

throughout the organization. After some time all of these departments (except the largest, vehicle electronics) were joined together as one department, i.e. the vehicle electronics department. The mechatronic development follows to a great extent the traditional systems engineering V-model (e.g. Möhringer 2003). The focus, however, is more on the integration and testing rather than the creation of requirements; this is elaborated further in the next section.

As more and more functions are realized by mechatronic systems, there has emerged a need to better manage the relationship between operator function, software, and physical component (Figure 3). One interviewee comments on this idea as follows:

”Most important is to work proactively so that we focus on the right things.”

One means to do this has been to model the product so as to easily visualize the relationships within the product. Management of these functions in a function-oriented development process is a major challenge for the current development teams, and means to manage the complexity are being worked on. The relationship between the function and the ECU system is going to need some sort of mapping. As electrical functions are abstract and realized first when initiated by the operator of the vehicle, they are not easily modelled and connected to the physical world. An operator function could in this context be defined as an electrical-related service that creates explicit benefit for the operator. To put the user in the centre of functional modelling makes it possible to assess the benefit of the function and to highlight the user benefit. One way to manage this interface from function to software to physical hardware would be to introduce a sub-function element between the function and the physical system.

3.2 Projects and line work

According to the respondents, the line organization dominates at Scania. This is natural since product development has a history of predominantly taking place in the line organization. Indeed, projects occur and are typically used as a cross-functional instrument to establish collaboration and responsibilities, when leaps in technology or new systems are investigated. The managers in the line organization are to a high degree involved in the product development, and their responsibility is comparable to that of a chief engineer. Because of this, the managers normally have long experience of both Scania and product development, often from other departments as well as the current department. It is a common practice for managers to switch places after some time at a position in order to make cross-functional collaboration more efficient. This has been shown to increase the personal network and the understanding of different development tasks, which implicitly supports balancing of overall product properties. As one example, the managers of Vehicle Electronics switched position with the manager of Engine Electronics in order to improve the cooperation between the two departments.

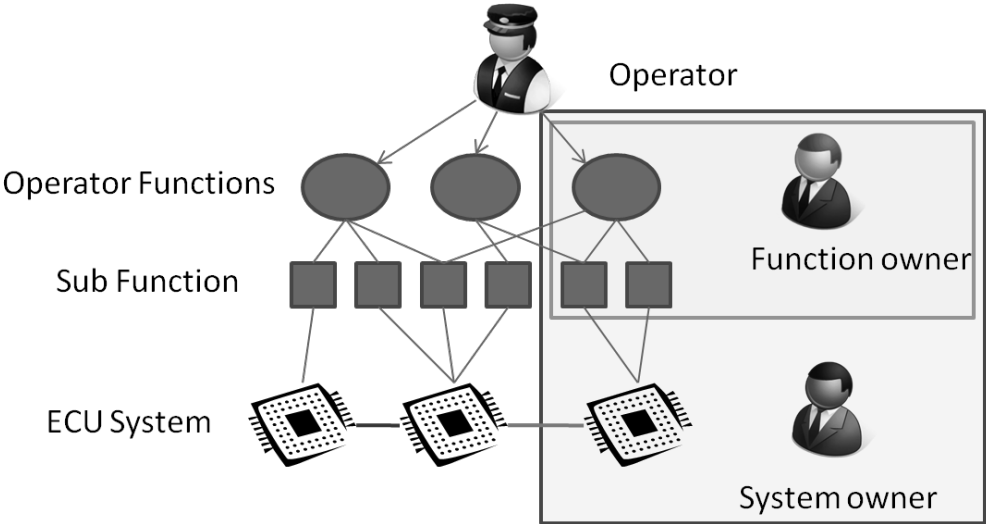


Figure 3. Schematics over the operator functions and the organizational counterpart

3.3 The product development process and roles

There is a product development process that describes the general flow and how products mature. However, the process is less detailed than at other comparable automotive companies (compare to e.g. Bergsjö, Vielhaber et al. 2007). There is a general belief in the individuals' capacity to solve the tasks themselves, rather than the belief that a common process will eliminate errors. This is particularly true when it comes to the test procedures at Scania, which are extensive in both time and resources. In terms of the V-model, the right leg of the V-model (integration and testing) is more defined and structured than the left leg. Thus not really considering the process of defining and refining requirements and product solutions. This is further expressed by one of the interviewees:

“We do a lot of field testing, test driving. It is by test driving the vehicle that we fully can evaluate the product's properties.”

From the questionnaire it is also possible to identify that work methods within Scania tend to focus more on product issues than on internal issues. This is in conformity with the emphasized product and customer focus experienced within Scania. Even though the line is said to be dominant, the respondents do not consider Scania as a bureaucratic company. Thus they find in general that it is easy to get things done. Possibly this reflects an adequate level of formalization and empowerment of responsibilities within the organization.

The separation of function and system within mechatronic development has to some extent found its organizational counterpart, as function owners are appointed apart from the already existing system owner (Figure 3). From the organizational perspective, the function owner has a much weaker position than the system owner, since the function itself is abstract and does not contain hardware like the complete system does. This is an area that needs to be further developed in order to transfer “power” from the system owner towards the function owner. Since the function is closer to the user of the vehicle than to the system (ECU system), this could potentially improve the driver's experience and satisfaction with the vehicle.

3.4 Innovation and technology development

The main part of this subsection has been derived from the quantitative business study. Even though Scania has a conservative view on the introduction of new features in the product, the general response from interviewees is that employees consider Scania as an innovative company. At the same time, their responses indicate that new technology should not be introduced too fast (thus before assessing robustness and customer value). This factor shows that quality is more important than time to market. From the designers' perspective it is hence very important that the product is launched with features that are properly tested and verified in many possible configurations and environments, in this way the uptime of the product can be ensured.

Long-term perspective is regarded by the interviewees as a key factor in being a market leader. Generally, Scania seems to adopt long-term perspectives, also when it comes to investments and costs. It seems that Scania would extend the time for testing and calibration of a product/feature if there is a significant risk of failure of that particular system. A higher cost in product development for a lower cost later in the product lifecycle is seen as a healthy choice, even though there are current tendencies towards cost savings without fully considering the customer value, in product development as well.

According to the responses, it is not conclusive whether or not Scania is good at learning from other companies and benchmarks of competitors. At organizational level, Scania is apparently good in adopting lean influences, e.g. from Toyota. However, there seem to be some deficiencies in the benchmarking of competitor products. Scania positions themselves as a follower in most technical areas of the product, and focuses only on a few prioritized properties with the highest customer value. Neither is it conclusive whether Scania's suppliers are good at meeting Scania's performance requirements. Some answers indicate that smaller suppliers are better than large suppliers in following Scania's specifications. Actually in some cases Scania has moved from outsourcing to insourcing in order to better manage the product properties, e.g. engine control system.

3.5 Working with requirements and properties

At Scania it is seemingly sensitive to talk about requirements and formalization of the process. In order to talk about these things in an indirect way to the interviewees, the focus of the interviews was on properties, and on how to manage and balance properties throughout the development process.

In general the belief is that it is good to have a clear goal of what the new product is supposed to do. There is often some sort of task, or description of what to develop in a new product development project, but it can hardly be seen as a rigid requirement specification. In addition to the development task, there are some general guidelines when developing a new product. A few of the most important are that the solution should be robust, regarding both breakage and wear, but also regarding flexibility and compatibility with many modules and towards future systems and solutions.

It is basically the task of the product-developing engineer to state the requirements on the product that she/he is developing. These requirements are then the basis for the test specifications. However, to some extent documents are established too late, or even after a product solution is chosen. This makes traceability to the initial requirements and the creation of the solution difficult.

Concerning the complete product (finished truck or bus) there are some general defined properties regarding both the performance and the prestige of the product. Properties related to cost of ownership and fulfilling legislation are important. However, there are difficulties in managing (other) high-level requirements/properties across the product.

These high-level properties are often difficult to assess for a product developer, but are important when the product is balanced at a higher level. Things that cannot be delegated to a specific engineering team need to be managed at cross-functional meetings where the “other” properties can be traced. This type of balancing is made by different boards and focus groups with a large number of managers present. Further, the even more abstract prestige attributes are still more difficult to assess objectively. These properties are also connected with marketing and the overall perception of the Scania brand. There exists today no clear means of managing the prestige properties from the perspective of the engineer, and no clear (or informal) organizational ownership of the prestige properties – for example, the more concrete performance properties.

In order to detach the responsibility of a property from a specific development team or module of the product, some organizational changes have been made. This has led to the creation of a product planning organization, with responsibilities for each property and responsibility to find synergies between the organizational units. The product planning organization thus manages the properties outside the main product creation process. In this context, it is important to stress that the product planning department is quite new and hence a weak organization. The product development organization is very strong compared to the supporting organizations in general, such as product planning and IT. Product development and production are very dominant organizations at Scania.

Commonality and carry-over are mostly seen as positive for the overall properties of the product. This can be compared with the general belief in modularization, and particularly the idea of “performance steps” in managing variant complexity. This is the idea that most customers’ needs can be satisfied to a large degree with standardized steps rather than complete customizations.

3.6 IT support for requirements and properties management

Scania has a quite conservative view on IT systems. This can be seen from the fact that the company prefers using older stable versions of IT systems rather than the latest versions. It is also a quite slow process to introduce and try out new software. In the embedded systems development, most specifications and documents are written Word documents that are secured in a document management system. Trials with requirement management software for embedded systems development are tested out from a small (and growing) group.

In comparison with other automotive companies, the internal IT department is considered quite weak. As a result, the coordination of the business has been from a business perspective rather than from an IT perspective. This view is coherent from both the business and the IT department. It is (almost) always the business department that has the deciding power when it comes to use and introduction of new IT systems. This also happens often without the involvement of the IT department.

4. Discussion and outlook

Since Scania is to a large extent an informal organization with informal work procedures, which relies heavily on the individual, it is important to improve the organization stepwise, taking great care not to move too fast. One of the interviewees expresses a need for increased formalization with the following statement:

“We ought to be better in gradually freezing the goals during the development process.”

From the authors' perspective, Scania is a well-functioning machine that needs some fine-tuning regarding, for example, documentation and information management which is discussed in the following passages.

4.1 Supporting requirements engineering in an informal setting

The first research question concerned: *What support for requirements management would be beneficial, regarding requirements management, within Scania CV embedded systems development?*

There is a great need for information traceability and quality control of the information and documents created during a product development project. In order for Scania to make as good documentation as they make products, more time needs to be spent on documentation and facilitating for co-workers to quickly get informed concerning important decisions and tradeoffs made during the development. For example, the informal procedures could be supported by some sort of lightweight requirements management system or decision support system. For instance, Toyota A3 documents (Liker 2004) could be used in order to quickly and correctly show decisions taken during a product development project.

From a requirements engineering perspective, product planning and its involvement must be considered. The current state of practice seems to work well and one must be prudent when implementing changes in it. Nevertheless, product planning can support the product development organization by providing a complete picture of the overall product and its properties. Having a weak product planning organisation is probably one reason for having a weak requirement documentation early in the development projects.

When it comes to more detailed mechatronic functions and ECU architecture, more powerful IT-tools need to be incorporated in order to manage the development complexity. This is already done, for example, with signals on the different communication buses.

Another perspective is the well-defined process for testing a developed system solution. Since the process is well-defined, it could probably be implemented in an ordinary (commercial off-the-shelf) requirements management system. For considering more than just requirements verification the implemented system for requirements and product data management must be able to manage the flexibility and the unique ways of stating and following up requirements at Scania. The standard IT tools put a lot of effort into defining requirements early in the development, which is a practice that is not used to a large extent at Scania. This is, however, something that can be improved, and something that is in general required (but not enforced) by the use of different requirement documents. The requirements definition is currently held back at Scania in favour of rigorous testing and generally evolutionary product development. This practice is not available as an “out of the box” solution from software suppliers.

4.2 Increasing formalization

The second research question concerned: *What could be a suitable degree of formalization in this context?*

It is important to remember what has made Scania successful in the past, not trying to formalize everything at once. It is always difficult to assess the “optimal” degree of formalization of any organization. In the case of Scania it is obvious that the company traditions are in favour of low formalization, at least in the initial phases of product development. The degree of formalization is then

higher towards the end of development, which seems reasonable. The need to better manage the early and middle phases regarding knowledge capture, reuse etc. makes it essential to increase the level of formalization in these phases. The important thing is to do it in reasonable steps and to be prudent regarding the current legacy.

A suitable way to start would be to standardize documentation and actually follow up on the creation of documentation. A good beginning for this would be, as mentioned before, the creation of A3 documents by taking inspiration from Toyota. The practice of A3 documentation is also used at Scania in a few departments, which gives the approach an internal encouragement. These documents could be used to document a product solution and to suggest improvements in order to start up a product development project. These A3's could be stored and archived electronically in the current document management system, or possibly as information in a structured wiki. (See Figure 4.) The separation between the formalized (production-ready) documents and the informal documentation could then be related to each other by e.g. links in a wiki.

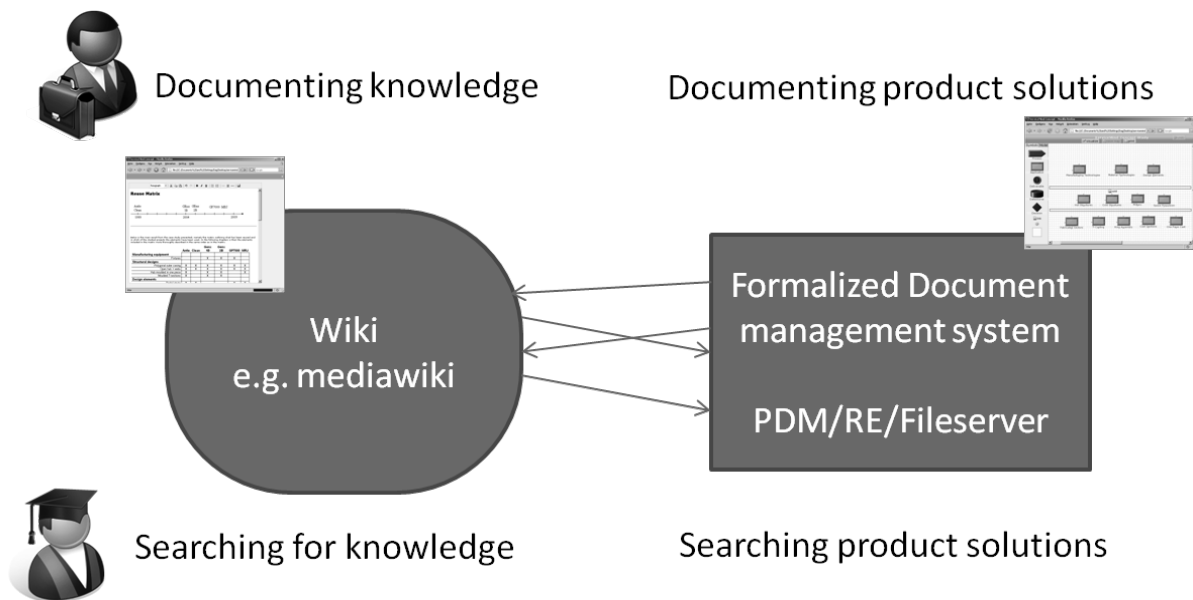


Figure 4. Relationship between formal and informal documentation

5. Conclusions

The business studies performed at Scania yield the following conclusions regarding the potential for requirements and properties management and the need for formalization:

- The majority of the key informants express a need within the company to formalize “knowledge”. However, considering the historically proven efficiency of Scania CV, this stresses the importance of respecting the current engineering culture, including the lean influences.
- Formalized requirements management does not exist at Scania today. However, the requirements are managed informally by delegating responsibility to the designers and focused meetings for balancing the complete product. This procedure is natural since the individual engineers’ knowledge and actions are highly appreciated.
- There is a clear priority among properties and requirements related to e.g. cost of ownership. However, there are difficulties in managing (other) high-level requirements/properties across the product. Things that cannot be delegated to a specific engineering team need to be managed at cross-functional meetings where the “other” properties are difficult to trace. This is why organizational changes have led to the establishment of a product planning organization to manage the properties, outside the main product creation process.
- Properties and requirements exist in the back of the head of each designer. But properties are perceived as being difficult to connect to detailed design tasks. This indicates a need for

visualizing and communicating the full picture of requirements for an overall product as well as sub-solutions.

- Prestige concerns the image of the product, and is a property that the co-workers within Scania regard as difficult to manage within the design work. It is also inherently difficult to describe such properties using objective terms.

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