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Requirements Handling in Multidisciplinary Product Development – A Company Study

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Abstract. When developing new products there are a multitude of requirements from different domains to consider making it a multidisciplinary activity. It involves stakeholders from the company and from the broader society. Requirements come from for example the customers, the production facility, suppliers, and governmental agencies placing safety and environmental regulations on the product. To manage all these heterogeneous requirements, a need of formalization and support emerges. The requirements can be managed using IT support. This functionality is often provided in contemporary PLM-systems. In this paper, it is investigated how a large industrial company with in-house design and manufacturing of consumer products formalize the requirements and handles them through the product development stages. The study involves corporate documents and interviewing staff from several departments of the company. Results show that while some aspects such as compliance with health and safety regulations are well supported, others are being addressed differently in each project with little formalization and IT support. This increases the risk of extra iterations in the development process. The paper discusses how to mitigate those risks and highlights some areas of possible improvement of the practices and IT support in product- as well as in production development.

Keywords. Product Lifecycle Management, PLM, Product Document Management, PDM, Requirements, Platform, Concurrent Engineering

Introduction

In engineering design there are many requirements concerning the product being designed to be considered. These comes from various sources. Examples include the market as the perceived wants and wishes from the customers as well as governmental legislation typically involving health, safety, and the environment. Requirements on product sustainability is becoming increasingly important. Requirements are coming internally from the company to enable efficient manufacture of the product or to source it from suppliers. Many requirements originate from packaging and logistics. Clearly, requirements are very often multidisciplinary and involving nearly all functions in a company when developing a new product. That is why a need for a transparent and traceable way of following the requirements throughout the development process is

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needed. This has been known for a considerable time and much research has been put into what is referred to as Requirement Management (RM) resulting in both methods and software. The term RM is extensively used in software development. In the development of physical products and services the terms seem to be less prevalent, but there is still a need of managing the requirements throughout the development process. RM is a useful term and will be used in this paper. RM includes taking the requirements on the top level i.e., the complete product at the start of the project and then gradually refining them and distributing them to the subsystems and components while developing the product. It also involves tracing the requirements though the development stages and keeping track of the validation and verification.

RM has become one of the more important research strands within PLM [1]. The multidisciplinary nature of PLM means that interoperability between different disciplines has emerged as important [2]. There is currently a gap between RM and the increasing complexity in developments project as for example how RM should be supported by the into PLM-systems [3, 4].

In the study reported in this paper, the RM in a large industrial company is investigated. The purpose of the study is to find the state of practice in RM and to identify the major challenges for the company and discuss how they can be addressed. The company is currently in the process of defining a new PLM system to integrate between the different functions and address RM throughout the development process. This study is intended to help direct how the PLM-system should be configured guided by the state of practice investigation. It was found that RM currently is quite dispersed and rely to a large extent on project managers to integrate between the different functions in the company. Further, it is difficult to obtain an overview of the requirements and their verification to direct the product development projects. Another challenge is the interoperability between different systems since the different IT environments in the company are not integrated to a sufficient degree. The study has been conducted by interviewing staff and studying corporate documents. This led to a state of practice description of the technology and product development related to RM in the company. From this description, the paper discusses some important aspects of RM in PLM-systems and relate it to the company.

1. Literature

Formulating requirements and keeping track of them throughout the product development process is as mentioned in the introduction a highly multidisciplinary activity. When designing the actual product, it is often found that all requirements cannot successfully be fulfilled simultaneously. There are likely conflicting requirements in the product design at hand and thus it becomes necessary to make a trade-off between them. Indeed, engineering design can be characterized as the balancing of these trade-offs [5]. The result is that the requirement set changes continuously during the development project and must be understood on several levels. The requirement set needs to be broken down from the general level and applied to the product being developed. A well know way of explaining this within systems engineering is the German V-model (VDI 2004). The left side of the "V" represents the decomposition of requirements and the distribution of them into sub-systems and components. The right side represents integration into a complete and validated product. Keeping track of them is a difficult task making RM an important topic. There are several tools and methods that have been developed within

RM. For example, the Kano model is a well know tool for understanding customer requirements. Quality Function for Deployment QFD is used for prioritizing between the requirements. It does often not suffice to manually keep track of the requirements. To assist, there are various IT tools available such as Doors (ibm.com) and Jama (jamasoftware.com). IT support is especially important in large complex development projects such as the Iter project [6] or in medical device development [7]. Being able to accurately predict the consequences of changes to the requirements is of high importance.

Lately, in the recent 5-10 years, these tools are increasingly integrated into PLM systems. Major vendors such as Siemens and Dassault include them into their PLM systems enabling links between the product and the requirement to be defined and kept up to date. Thus, requirements can be followed up per item allowing for example product CAD geometries to be linked to the requirements and the validation of them such as simulations and test reports. This allows for a complete digital environment making it more transparent and traceable [8]. However, there are challenges in this. In the publication [9] it is shown that a complex set of interconnected changing requirements place very tough demands on RM. In [10] it is found what one of the more important demands are from users of PLM is in fact integrated RM. The authors use a Kano model to analyze what functions that are desirable in automotive development and found that 9 features including for example "Linking and tracing" and "Requirement identification and capture" are crucial for RM tool user satisfaction. In another paper [11], the same authors have evaluated the RM tools in a collaborative scenario helping in understanding the considerations that companies need to take when configuring RM tools in their organizations. Viapiana [12] shows that PLM requirement traceability can be enhanced by the use of the requirement-functional-logical-physical approach. It is demonstrated on formula student car in the Dassault 3D experience® platform.

The PLM integrated RM tools are mainly focused on the product development process. However, several authors address the need of integrating production [13, 14]. In [3] it is stated that, in addition to PLM, the most important systems for handling production data is Enterprise Recourse Planning (ERP) and Manufacturing Execution system (MES). In [15] an integration between these three systems is proposed that will make it possible to progress requirements between the functions. The integration is done via Rest API.

The term *product platform* is often used to describe a set of components that can be configured to form several product variants [16]. They are referred to as "platform products" [17] (page 20 in the reference) However, the term may be extended to include the representation of the product knowledge and not only the set of configurable components encompassing all product knowledge. To make the distinction it can be referred to as a design platform [18] investigating the connectivity within a design platform. Such platform is depicted in figure 1.

To conclude from the literature study there are several well-established models, tools and methods for finding, elaborating, and prioritizing between requirements. However, the IT support for the process is still of an "islands" character where some parts are addressed but there are still no complete suggestions of IT handling of the multidisciplinary nature of requirements and keeping track of the progression of them throughout the whole development process. Presumably, the needs are related to the type and size of organization requiring an in depth understanding of the organization when planning the IT support for RM.

2. Method

The current paper was written as a part of a larger research project encompassing a high number of interviews. This paper is a sub-part of this project and involves two rounds of interviews. The first round concerned the state of practice in digitalization in the studied company. This was followed up by a second round of interviews focused on the requirement handling and the IT infrastructure for it. The second round of interviews were conducted in the fall of 2021. It involved one staff from engineering, one engineering manager, one from staff from production and one from the IT/PLM department in one of the companies. Data was also gathered via the study of corporate documents that the researchers were allowed "eyes-only" access to. The documents describe the process for new product development, the product structures and the test codes and reporting of tests. Based on the interviews and the supplied documents, a state-of-practice description included in this paper was written. It was noted what parts of the RM that the staff perceived as challenging. From the description, a future IT architecture to solve the identified challenges could be proposed and discussed in the paper.

3. Case Company

The company is large with more than 4Bn Euro in annual turnover and over 12000 employed worldwide. The products are mainly forestry and gardening equipment. The company has a longstanding tradition having been a supplier of various consumer and military goods for several centuries. In this paper, the RM related to chain saws and other products is investigated. These saws are part of a professional product line. They are of high specification and intended for use in professional logging. The company sell their products to retail or directly to major customers such as logging companies or communities. The company´s product development process is now to an increasing degree being digitalized. Model Based Definition (MBD) has been identified by the company as important. Computer simulation both of product function and production process is increasingly used. A comprehensive PLM-system spanning several of the functions in the company is now being launched. However, the details of how it will be used for RM is not yet established.

The current state of the RM is described in sections 3.1 to 3.3. Section 3.1 describe RM on a general level in the company. In 3.2 it is described how the RM is applied to products in the company and the validation of them. Finally, in section 3.3 the IT support for RM in the company is described.

3.1. Requirement Management in the case company

As a manufacturing company of consumer products, the company is responsible for the whole requirement set. There is no counterpart to define requirements as a sub-supplier would have. The company must independently understand the needs and wishes of the customers, adhere to the legislative demands from governments on different markets and at the same time steer their sub-suppliers into suppling the specified product and consider the manufacturability of the products in their own production facilities. Being in the high end of the market, the company strives be a market leader, regularly introducing technical innovations on the market. This is done according to the process illustrated in figure 1.

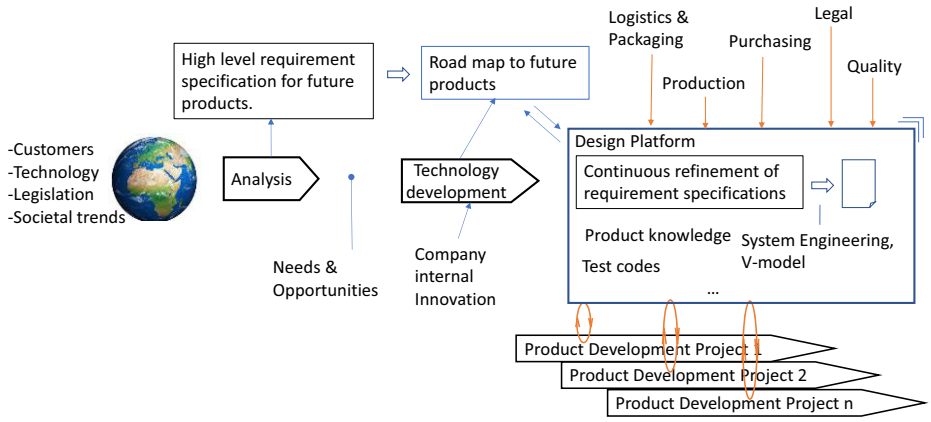

Figure 1. Requirements in the design platform.

Starting on the left-hand side of figure 1, the company closely follows the technological development, societal trends, the voice of the customers and the planning of new or updated legislation from the authorities. This can for example be done by attending branch exhibitions, following what is published about emerging technologies, following the political discussion on new legislation planning and taking part in standardizing committees. The data from these activities are analyzed so that the needs and opportunities can be identified. Thereafter technology development will follow to explore the potential of the emerging technologies and better understanding the needs from the market by for instance letting reference group test conceptual products. A "road map" is created to formalize the future product portfolio and to specify at what point in time the technologies will be introduced. The road map has a "general requirement specification" to show what will be required from future products. Close in time it is quite detailed but less so the further ahead in time. The technology development is also driven by innovations within the company. The knowledge about these emerging technologies can be said to belong to the design platform representing the body of product knowledge of the company. Conceptual designs are created and are gradually refined. Requirements also comes from most of the functions within the company such as production, quality, logistics and packaging and purchasing. These also gradually become part of the requirements specification of the products. When the conceptual designs are mature enough and deemed commercially viable, they are transferred to product development projects to fully develop the product and perhaps be put it into series production. After, this point, the development process follows a strict process with several gates. It is planned in detail and involve many more people than technology development. One or several project managers are appointed to create and keep the time-plan of the project.

One recent example of the process according to figure 1 is electrification which led to a new line of products. Years before the market introduction of the products, the company perceived and analyzed the trend of electrification, developed the technology, and gradually proceeded to developing the actual products. One other example is the emergence of the very strict legislation on engine exhausts in the north American market and the development of the products to meet these requirements.

3.2. Requirements applied to products

The requirements in the product platform are in many cases written on a high level and cannot be applied directly in a product development project. It is the responsibility of the engineering department to transfer the general requirements into measurable criteria on the product and its components, in principle working according to the afore mentioned V-model for breaking down the overall requirements and assigning them to sub-systems and components in their products. This resulting in a detailed requirement specification for the actual product being developed. This cannot usually be completed at a single point since it is necessary to develop the product components sufficiently so that it can be understood what needs to be specified and measured. Thus, completing the requirement specification is an iterative process. It must be possible to objectively verify that the designed product fulfils all the requirements, so a test plan specifying both virtual, and physical tests is simultaneously created.

The test plan is normally not created on a blank sheet of paper in each project. The company has long experience of developing this type of products so a great deal of the requirement and their verifications can be reused, perhaps with some modification, in the new project. Currently, there are hundreds of different published tests, called "test codes", available. Examples of test codes are climate tests, fatigue tests, exhaust tests, and corrosion and UV tests. The test codes consist of instructions of how to perform the test and how to interpret the results. They are part of the product platform, and they are continuously being updated. The company has purpose-built equipment and special test labs for conducting the testing. Some tests are performed in field conditions on complete products others on components and sub-systems in the laboratory. Testing is seen as part of the engineering development work driving towards improved designs. Many of the verifications are made virtually on computer models. It is known from previous projects how to create the computational models to study phenomenon and to predict product behavior.

The company have developed instructions on how to build these virtual models and there is an ongoing process to refine them as knowledge and computational technology is advancing. They are also verified by correlating them to physical tests. Not only the functions of the products are verified but also the product behaviors though the life cycle such as in manufacture and assembly. It is for instance verified by simulation that the dies in die pressure casting will fill properly, and that the product can be successfully assembled.

3.3. IT environment

The requirements specification is in the initial phases kept in a quite narrow circle of employees and kept as written documents on servers. As the actual development start there is a need to spread the information to more people and have a revision handling to ensure the latest version is available to everyone, especially as changes becomes more frequent. Here, dedicated systems for RM are in use at some departments. In particular, this applies to software development. Some departments have a document-based RM. However, the company currently has a quite complicated IT structure. Partly, this is a result of incorporation of acquired companies in some business areas. There are for example several different PDM systems in use. Efforts are ongoing to launch a companywide PLM-system including a more uniform IT support for RM. It will be CAD integrated and based on a commercial platform. The new PLM system will be item

centered and support assigning the requirements and the verifications to items such as CAD and FEA models. The company is moving towards defining their products in digital models i.e. MBD.

One important part of the requirements elicitation is to gather and analyze production data. Production data can give important insights in for example the manufacturability of the design. Designs that regularly causes stops and problems in the production should be highlighted to the engineering department to avoid the same mistakes being carried over to future products. Here is an IT interoperability problem since the production is managed in several different ERP and MES systems on different production sites. Statistical analyses of production data need to be fed back to the design platform. Currently this is carried out via excel sheets or similar.

When the design phase is completed, the product structure in the PDM system is imported into the ERP system with no direct system integration. Additional data such as production volume predictions are entered into ERP. The project is thereafter transferred to product maintenance mode in the PDM system, and the responsibility is handed over to the quality and production departments.

Every function in the company works with their part of the requirement set. However, the engineering function is central since it is their responsibility to design a product that fulfil all the requirements. A clear picture of the status of the requirement fulfilment emerges only at the gates in the product development process as all documents are compiled. As explained, engineering design very often involves trade-off between conflicting requirements, so having an active dialog between the department during the project is highly desirable. Therefor a continuous overview of the requirements would be helpful. The interviewees stated that this, in some projects, did work very well with a frequent and constructive dialog between the functions. However, this relies much on the employees. In some projects the communication has been less good resulting in things being overlooked with possible delays and retakes at the gates as a result. A uniform visualization and follow up integrating the different functions is needed. Here, an integration of the different IT systems could be a way forward.

The data and information related to requirements are kept mainly as written documents in local databases. It is therefore currently not possible to associate them with the products being designed. It is the responsibility of the engineering department to grasp the complete requirements set and assign relevant requirements to the products being designed.

4. Discussion and conclusion

The state of practice investigation showed that the company has currently a RM that is dispersed over different functions in the company. It is primarily the project managers who keeps track of the requirements and their validation throughout the product development process integrating between the different functions. Conflicting requirements becomes evident when passing gates in product development process.

However, a more proactive way of working could be achieved with improved IT support so that it quicklier can be understood where the requirements conflicts occur. With an earlier discovery, better ways to solve them can be worked out. It will also mean improved possibilities to follow the process from requirement formulation to the validation of them making the process more traceable and transparent.

The company is currently moving towards a companywide item centered PLM system. This is still in the planning stage and there are many decisions of both principle and practical nature to be taken over the coming years. Examples of questions to be solved are: What should the primary items in the PLM system be? Should the requirements and their validations be linked to the items in the PLM-system and how? How should requirements be represented in the PLM system? How should the PLM system integrate with ERP and MES at different production facilities?

When planning the future PLM, it should be kept in mind that RM is a dynamic and creative activity. Making the process too formalized will mean that the organization will not be able to react quickly enough to tackle design and requirement changes. It can be assumed that it needs to be flexible to accommodate different types of projects. What a good level of PLM process formalization is for the organization is yet to be discovered.

Since the company is actively moving more into MBD, it seems natural that the items in PLM should be the digital models, such as the CAD, FEA and CAE. It is certainly technically possible to link those to requirements and validation documents in the PLM system, but there are process related consideration to be taken. The systems engineering approach means that the requirements are broken down and assigned to the components of the product in a very dynamic way during the product development project. To best support this way of working in PLM, questions on how and to what granularity it is reasonable to represent them in the PLM systems needs to be resolved.

A better integration between PLM and ERP is needed. The transfer of the BOMs between the systems is an area of improvement. There is also a need to feed the production and quality data from current production upstream into new product development projects. The data need to be analyzed so that engineering can understand what can go wrong with the products and improve the future designs accordingly. Perhaps Rest API technology can be explored here.

Future work

Representing and tracing the requirements on different levels of elaboration including their verification and validations in the different lifecycle stages is the next planned step in the research project. It involves the PLM-system support for RM. Different PLM-functionality will be explored so that the transparency and traceability of RM can be improved resulting in a more proactive way of continuously following the requirements and their fulfilment.

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