COORDINATING THE ENGINEERING AND AFTERMARKET DISCIPLINES IN EARLY PHASES OF PRODUCT DEVELOPMENT

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Abstract

Product development is a complex engineering activity in most manufacturing companies, as it entails the consideration and elaboration of a wide variety of parameters. Early involvement of important cross-functions, e.g. manufacturing and aftermarket, facilitates great opportunities in terms of lowering lead-times and cost, and increasing product quality. But it does also complicate the engineering work as a broader range of stakeholders get involved earlier in the development process. This research work considers two parallel and integrated pre-studies, which are aligned towards the engineering and the support view of a future product. Organisational, procedural, method, and IT aspects are examined. The extension of this work will provide better possibilities to administer and process product information within a cross-functional product development environment.

Keywords: Product Development, Cross-Functional, Aftermarket, IT

1 Introduction

Many markets of tomorrow will facilitate large opportunities for the offering of functional products. That could be selling engines by the hour in aerospace or ton-kilometres in logistic services or to supply a particular information service continuously with a certain quality level for a specified number of users. For original equipment manufacturers that also uphold the position as service providers this will set demands for improvements in product and product support development, as the product's total lifecycle cost is tightly connected to the possible profit. Implementing mechanisms for considering maintainability and supportability aspects in product design will enable a more efficient use of the product, thus enabling functional sales and maintenance contracts. An early understanding of the evolving product design will facilitate possibilities to influence its supportability in a total cost-reducing manner, as well as it will imply better means for developing the product support system for maximum operational availability.

The purpose of design for operational feasibility is to reduce the causes and consequences of faults in order to reduce the costs connected to the product lifecycle [1]. To make a reliable system the functions that the system is supposed to perform has to be performed correctly every time they are requested. The system must also be maintained in order to assure a reliable functionality. Last it has to be surrounded by an organisation for performing the maintenance.

Reliability is defined as the probability that a system or product will accomplish its designated mission in a satisfactory manner for a given period when used according to specified operation conditions. Maintainability of a product has to be considered a major system parameter in the design process. Maintenance should be kept to a minimum because of the downtime of the product, while the product is kept reliable. This is made by carefully planning the future maintenance of the product while designing it. The goal should be to develop a product that can be maintained effectively, safely in the least amount of time at the least cost and with a minimum expenditure of support resources, without affecting the purpose of the product [1].

The goal of this study has been to assimilate a wide range of lessons learned from a pre-study in the manufacturing industry. In particular, important aspects for effective cross-functional development with respect to aftermarket performance are highlighted. Issues of interdisciplinary procedures for working with requirements engineering and concept development are essential cornerstones for sustaining aftermarket design variables throughout the pre-study. In addition, use of PLM (Product Lifecycle Management) tools, e.g. RM (Requirements Management) tools, CAD (Computer Aided Design) , and DMU (Digital Mock-Up) tools, are interesting to assess as they are used as a mean for communication between the cross-functions involved in product development. All-in-all, the study's goal is to assess important collaborative aspects when conducting aftermarket support development together with engineering in early stages of product development.

The research questions that have guided the conduct of this work are as follows.

- What characterizes a sound organisational setting when conducting product development with involvement by the aftermarket discipline?
- Which are the most important success factors, and opposite, setback risks, for an efficient requirements engineering and concept development, with respect to balancing the engineering and aftermarket interests?
- What distinguishes a feasible IT tool support for the aftermarket discipline in product development, and what are basic obstacles when implementing it?

The main research approach was an interview study including 28 interviews. The study also incorporated document reviews and some observatory studies of project management and design workgroup meetings.

The paper is structured as follows. Chapter 2 considers related efforts in the areas of design for operational feasibility, requirements engineering and concept development. Chapter 3 regards the method used and briefly describes the underlying industrial case. Findings are conveyed through chapter 4. The findings are discussed in Chapter 5, whereas conclusions are placed in Chapter 6.

2 Related work

There are several studies that depict the business case in designing for aftermarket [1, 2, 3, 4]. The need for smart solutions, as regards service and product support cannot be exaggerated. When the customer starts to look at the total cost of ownership the relative low price of purchasing a product is overtaken by in-service costs. Proper maintenance and product support can further prolong the lifecycle of the product, increasing the value of the delivered product.

Tjiparuro and Thompson [2] endorse the importance of maintenance in order to lower the lifecycle cost of a system. They conclude that working with maintenance aspects is difficult in conceptual phases because of the many conflicting requirements affecting the designer. The axioms of the research are: Simplicity, parts/components features, operating environment, parts identification and assembly/disassembly. The solution is to simplify by avoiding complexity, work with parts/components features, and to carefully consider the environment where to place a part/module. The concepts of aftermarket design are also described by Markeset and Kumar [3]. Their research suggests that maintenance is dependent on the designer's perception of several functions within the design process. A holistic image of the product will help to focus on lifecycle cost and availability as the target for optimisation. If this is done the properly product support and support can become a major source for both revenue and considerable savings.

A study with focus on the early stages and work with digital mock-ups to improve maintainability has been done by Di Gironimo et al. [5]. Their work included the proposal of a method for optimising the disassembly process. The EDIVE method gives a foundation for how to work with disassembly (maintenance) early in the development of complex products. Their work shows that it is possible for maintenance people to simulate using virtual hands and tools to evaluate the premature concepts. However the success of their model is not evaluated and the often conflicting requirements of assembly and disassembly make their hopes of optimisation without sub-optimisation difficult. The research presented in this paper does not sufficiently describe the business benefits by applying an early pre-project focus on aftermarket issues in the product development process.

In a study performed by Sutinen et al. [6] the use of a new tool for requirements management has been investigated. The study focuses on the organisational impacts when introducing new software and tools, where key difficulties lie in education and commitment. Sutinen also suggests a guideline containing several points where the use of pilot projects is important. It also states that improvements are difficult to observe immediately. The study does not in detail evaluate the impacts of different and new upcoming stakeholders in the early phase.

The advantages of cross-functional development has been promoted by Almefeldt et al. [7], who proposes an extensive interdisciplinary requirements analysis and validation dialogue in early phases of product development in order to obtain a base of shared knowledge and system models. Their results are however synthesizes from a broad empirical base, not incorporating or focusing specific aftermarket aspects in detail.

Another approach that aims at enabling an early consideration of service aspects in product development is that of Weber et al. [4]. The potential of product service systems are discussed by them. It is declared obvious that the integration of products and services into one package is going to add value to a product that traditionally was considered either product or service. In their work, Weber et al. 2004 suggests an integrated way to deal with customer integration named Product-Service Systems Engineering that is supposed to bridge the gap between engineering and business administration departments. However, a weakness with their methodology is that it has not yet been subject to industrial verification.

As being elaborated out of a real industrial cross-functional pre-study, this work contributes to research by highlightening a wide, but still coherent set of practical problem areas, with respect to integration between engineering and aftermarket. Synthesized recommendations applicable to a large industrial setting are provided in order to enable a more efficient design work, including issues beneficial for the aftermarket businesses.

3 Method

3.1 The case

This paper is based on interviews with people active in, and observations from a larger pre-study in the manufacturing industry. The company subject to study is a large original equipment manufacturer, which is one of the world's largest in its areas of business. The pre-study's aim at the phase(s) subject to study is to deliver a consistent and balanced set of product requirements and technical concepts, very similar to what Pahl and Beitz [8] outline as *Planning and Clarifying the Task*, and *Conceptual Design*. The purpose is to enable later detailed design. A novelty for the considered company within this pre-study is the early incorporation of several large cross-functional efforts into the total development process, whereof aftermarket is one. These cross-functional efforts regard both development of the functional system in itself, and evaluation and influence aspects of the engineering side, i.e. the evolving product definition. Driving factors behind are an ambition to shorten lead times from early decisions to industrialisation. As functional sales, including maintenance contracts and similar are anticipated to take an increasingly share of the total business in a near future, aftermarket performance becomes more and more important too.

3.2 Data Collection Method

The main research approach was an interview study including 28 interviews, in most cases lasting for slightly more than an hour at a time. The study also incorporated document reviews, thus considering key information archives with respect to the pre-study subject to study, company internal instructions and standards, besides running IS/IT project information. In addition, some observatory studies of project management and design workgroup meetings where performed as well. A total of seven meetings were observed.

3.3 Interview Strategy

The interviewees where selected together with company representatives in order to enable a comprehensive picture of the issues. The selection of interviewees was carried out following a purposive sampling strategy [9]. By using this approach it is not possible to make a statistical generalization, however it is the belief of the authors that the sample will show a representative cross-section of the organisation while keeping bias to a minimum. The number of interviewees and their assignment alignment is shown in Figure 1.

The interviews were conducted between May and August 2005. The interviews where divided in two groups. One half taking place in May to June, in order to give a broad view of the whole project. The second part of the interviews took place in July to August, with the focus to further penetrate the subject and to ask those questions that the first round generated.

Figure 1. Interview selection

3.4 The Interviews

The questions in the first series of interviews were of open character, in the way that a general topic was specified and the interviewees where free to answer the question with their own words. The purpose for this was to guide the interviewee rather than force answers with directly formulated questions, in accordance to the recommendations of Robson [9]. In the second series of interviews more specific questions where asked, in order to respond questions rose during the first phase of interviews. Questions were withdrawn or adapted to correspond to the different positions and experiences of the interviewees. The questions asked where first a set of standardised questions and then those where followed up by more role-specific questions. For example, interviewees who said that they never used digital mock-ups were not asked the follow up question regarding which software they used. The questions where adapted on the basis for what they were expected to know regarding their current position in the company. The interviews where recorded, and a short document containing the major points was send for review to the interviewees. The interviewees were hereby given the opportunity either confirm, or alter their statements in a way that suited them.

3.5 Data Analysis

The data collected has been refined and reduced in a systematic way. The first step to reduce the data was when the interview protocols where written. After the first series of interviews a workshop was held where the data had to be reduced further. Findings where categorised in scope and out of scope. The in scope part of the material constituted the foundation for the second series of interviews. After the second interview phase all relevant findings where gathered and further refined. For the results presented to be credible, transferable, dependable and confirmable [9] the findings have been tested thoroughly in seminars and by the intended users. The draft paper has also been reviewed by those interviewees who requested so. A general workshop has also been held in order to further validate the results and approach of the study.

4 Discussion of findings

This section comprises findings from the study and interrelated discussions. The presentation starts with organisational matters, and then turns into procedural and methodological aspects of cross-functional development. By the end of the presentation some PLM tool adaptation and implementation issues are highlightened.

4.1 Overall organisational issues

A co-lateral division to that of product development, in the studied company is assigned for product planning. Typical tasks of this division include planning of new products with at least a decade-long perspective, initiation and ordering of product changes, and validation of upcoming product's commercial viability. Regarding the studied project case, product planning's role is to identify and convey customer needs, negotiate product requirements, and to accept developed solutions, all with respect to product development. Product planning in itself is a large organisation which is subdivided into several divisions with functional or product line responsibilities.

The development project observed is divided into a set of coordinated and mutually dependent pre-studies, see Figure 2. The largest is of course that of product development (~engineering). In addition, pre-studies are conducted in the purchasing, aftermarket, and production areas. Of these, only aftermarket develops technical solutions and services that directly connect to the end-product.

Product development is organised according to a zonal subdivision of the product, with several sub-studies being performed simultaneous and synchronised. Each such sub-study is responsible for coordinating the development effort taking place in a number of workgroups.

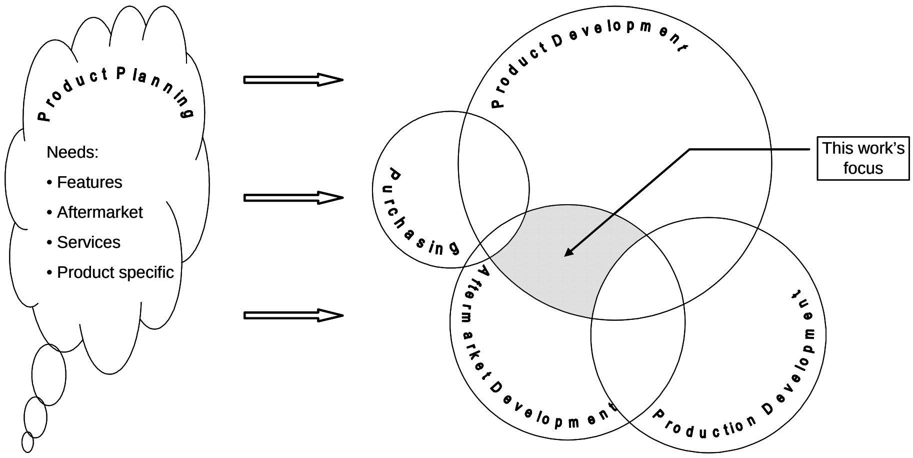

Figure 2. Organisational and relational aspects of the pre-study

Traditionally, product planning has always set overall pre-study goals for product development. The relationship between the delivery and customer organisation during preceding pre-studies has been relatively informal, based on cooperation between area responsible personnel at product planning and architects in product development. This has however shifted in the pre-study observed, turning into a more formal relationship. The introduction of Systems Engineering as a pre-study methodology for managing the increasing product complexity has enforced a stricter fixing of these organisational boundaries, as well as formalized the communication between participants in the pre-study. Product planning has been expected to formally agree and decide on detailed product requirements, solution proposals and such. However, product planning has not been able to fully comply with this new way of working, lacking in both staffing and accustomedness in Systems Engineering. This has lead to many conflicting and non-validated requirements on the product to be developed. The observation is valid for the aftermarket area as well.

As complexity and number of personnel contributing to the overall pre-study is high, participation in various decision bodies becomes important for interested parties and actors working across the business. Of special interest are those forums in product development that are set up to execute comprehensive design decisions and manage targets. Since aftermarket applications are highly dependant on technical solutions across the product, participation and influence in such groups becomes essential in order to ensure that no important in-service aspects are disregarded. However, as the pre-study has progressed, aftermarket representation in most decision forums in product development has been weak. As a consequence, aftermarket considerations in developed concepts have been rather low. This is most likely due to a sequential outlook and tradition were, in the eyes of designers, aftermarket and also manufacturing ought to have little power to influence the product design, left behind to perform subsequent development. This state of things has also been observed in preceding studies, e.g. Almefelt et al. [7]. A further emphasis on aftermarket representation in key design decision forums is one of the fundamental recommendations out of this work, as it will facilitate a parallel and a more effective aftermarket development.

4.2 Aftermarket pre-study organisation

The Aftermarket Pre-study is assigned to develop support for product associated services, e.g. methods for maintenance & repair, spare parts management preparation, and tools for product diagnostics. The aftermarket pre-study organisation has two parts. One is dedicated to concept development of product support related services. The other one is dedicated towards evaluating and influencing product development, thus to promote sound technical solutions for the aftermarket support system. This part of the pre-study is what has been in focus in this work, see Figure 2. Work and necessary co-operation within product development is accomplished through a large number of workgroups. Some of these concern packaging of geometrical parts, and constitute where the aftermarket pre-study has chosen to deploy its impact. A series of specialists with different functional competence monitor the aftermarket aspect in these product development workgroups. These specialists do part time in the concerned pre-study, but are coached and coordinated by some project full-time participants, i.e. the aftermarket coordinators.

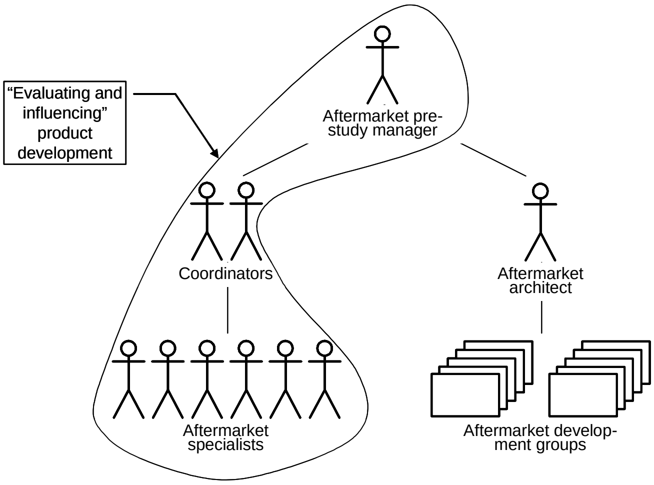

Figure 3. Aftermarket pre-study organisation

The observed case represents the first time such a large aftermarket pre-study has been launched in parallel with that of product development. One of the main issues that have emerged within the aftermarket pre-study, as regards the part working in connection to product development, is hardships in defining measurable criteria for continuously evaluating the effort. Evaluation of aftermarket requirements fulfilment should of course be a central element in pre-study follow-up activities, but what is missing are means for measuring progress when the concepts are vague and not fully integrated to one another. The design review is a recurrent activity for all pre-study participants and functions. Between those reviews, the designer receives continuous feedback through the evolving product design, which is very tangible. The aftermarket engineer has however a more intangible task, left over to analyse design work, and if necessary to persuade changes. This way of working provides few means of feedback regarding day to day activities in between design reviews. Even though aftermarket related product requirements are used to guide the work, few means for prioritizing and verifying the design result in the eyes of aftermarket are supplied. Also, the unbalanced relation between the overall pre-study's size and aftermarket's sizing of its attempt of influencing product development makes such a task hard to accomplish.

4.3 Requirements engineering

The product development process at the studied company has been fairly stable for a large number of years. But in connection to the initiation of the observed pre-study, a new and changing methodology for running the early phases of a project has been introduced. Based on core Systems Engineering [1] this process aims at delivering a complete set of balanced product requirements and technical concepts. Different parts of the organisation are intended to speak the voice of external (customers, legislation, et cetera) or corporate (purchasing, manufacturing, aftermarket, et cetera) pre-study stakeholders. These stakeholders are designated to not only to bring forward different their particular needs, but also to agree on product requirements and to accept technical solutions. With respect to requirements, several areas are explicitly related to aftermarket operation, e.g. soft offers, different kind of extended businesses, or the set of constraints that the existing aftermarket support system wish to place. As regards technical concepts, the complete product is subject to aftermarket consideration as many parts of it will be either repaired or maintained or both during the total lifecycle.

Many difficulties arise when introducing new process methodologies simultaneously with running an aftermarket pre-study in parallel to product development for the first time. As the number of stakeholders putting pressure on aftermarket performance is high, the sheer number of aftermarket related requirements has become large in the study observed. Many of these do not fit recommended properties for a requirement as stated by Hull et al. [10], e.g. that requirements shall be atomic, unique, feasible and verifiable. Either they are too indefiniteness, or too definite, i.e. almost prescribing a certain solution. Altogether, this adds to a position when it becomes hard for product development and other solution providers to sign-off and thus accept responsibility for the requirements.

Development of complex products often implies extensive requirements engineering. In combination with a heterogeneous and complex organisation, the need for negotiations between different stakeholders grows to handle and balance sometimes conflicting needs. To effectively deal with these issues call for a sufficiently manned Systems Engineering organisation, consisting of customer representatives, solution providers, and sometimes specialised requirements engineers. In addition, clear and well-stated requirements are needed, with a minimum of overlaps between different areas. Observations from the studied company strongly indicate that a shortage of staff resources specialised to support the requirements engineering process leads to unbalanced prerequisites for continuation of the development. The resulting outcome tends to be very solution-oriented, rich on details, but short of considerations regarding the overall system and product performance. The structured requirements-driven development subject to could however, even if not fully implemented, is regarded as an improvement respecting the company legacy.

4.4 Concept development

Design and integration of technical solutions is the main business for engineers active in product development. The creation, evaluation, selection, and refinement of solutions are referred to as concept development, and are an integral part of the Systems Engineering process with respect to the studied company. A systematic approach to concept development could comprehend the use of many detailed and structured design methods, e.g. use of functional analysis, brainstorming, morphological matrices, and concept scoring. Many times such methods call for the use of cross-functional teams in order to perform efficiently with respect to the produced outcome. A particular branch of methods sometimes used in concept development and in later detailed design phases are the variety of quality methods.

Despite the fact that the observed company has a well established development process, no extensive use of established design methods for concept development has been noticed. Even though the Pugh concept evaluation method [11] is prescribed by internal instructions to support the Systems Engineering process, lack of transparency for aftermarket engineers in the growth of concepts has been shown evident throughout this study. In the workgroups observed, of which a larger part concern geometrical packaging, the use of alternate concepts and use of the Pugh method have been rare. The structure of work observed has been stamped of ad-hoc routines. As aftermarket representatives participating in engineering contexts almost by definition posses a shortage of product development experience and design methods skills, their ability to promote the evolution of supportable technical solutions is limited. A further systemization of the effort in work groups, i.e. well considered and increased use of methods for concept development, would amplify the effects of aftermarket contribution. Besides, that it would support compilation of better solutions.

The general task for aftermarket specialists contributing to product development work groups is to make sure that ill-considered and costly solutions are not introduced into the product as regards its in-service phase. Within the conducted study two classes of aftermarket engineers have been paid some further attention, namely the parts planners and the maintenance engineers. Parts planning from a product perspective regard spare parts preparation, including aspects of branding and purchasing. The phenomena of variety and commonality are important to monitor for these engineers throughout the development process. Maintenance engineers are in highly involved in improving the maintainability performance of the product, i.e. the ease, accuracy, safety and economy in maintaining the product. Both these categories of engineers have in their own, and their co-worker's eyes been struggling a lot with the high degree of indefiniteness that characterises the pre-study. The parts planners have been forced to struggle with inconsistencies in the product description, a result of simplifications for the purpose of speeding up the process, which has led to problems with identifying variety amongst product variants. The maintenance engineers have had certain problems with retrieving basic data for their methods of analysis, e.g. assemble and disassemble. They have however been able to perform the intended set of analyses almost from the beginning of the pre-study.

4.5 IT tool usage

Use of CAD tools and virtual models are important tools for creation and integration of concepts. They are also utterly important as means for communication and decision-making in the work groups which co-ordinate the development. Meetings and reviews are based on all participants' use of virtual models, resulting in that each individual's level of influence not only depends on specialist knowledge and accustomedness to work methodology, but also to their ability to communicate by means of these tools. Aftermarket specialists assigned to evaluate and influence product development in the conducted study have a comparatively low level of familiarity with these tools, which has diminished their level of penetration.

With respect to the business of evaluating and influencing product development two classes of IT tools becomes particularly interesting, namely tools for requirements engineering, which was new for all personnel, and geometrical modelling tools, which was new for the aftermarket personnel. At the business subject to study, one requirements database is used to store, manage, and distribute requirements. For design, multiple CAD tools are used to develop different parts of the product. In addition, multiple DMU tools are used to mediate the evolving product design and to create virtual prototypes at freeze periods.

The RM tool used in the pre-study is a fairly simple but scalable application that consists of basic features such as classification, structuring, and allocation of requirements. A wide range of attributes are used for various requirements engineering sub-processes. The implemented solution model is however basic, and not integrated to other design tools. A co-ordination problem that has evolved during the pre-study is that not all parts of the overall pre-study are using it, which has rendered difficulties in controlling configuration of requirements breakdowns. Other problems include the late entry of requirements into the tool, which has disturbed the sign-off process quite heavily. As the tool has been introduced along with a new formal process for requirements engineering and concept development, in a still adapting organisation, many roundabouts with respect to the tool has been done by stakeholders and solution providers, thus rendering difficulties to have a clear view of statuses of the requirements in the ongoing development.

Even though the introduction of this new RM tool have gone together with a quite extensive training and other supporting measures, one should not underestimate the difficulties in getting a large organisation to assimilate to new tool. To be able to balance different areas of interest, or to prioritise a certain matter, call for a widespread use of the tool, thus filling all parts of interest.

The geometrical definition is fundamental for the type of products concerned, even though many functionalities are nowadays implemented through electronics and software. Many designers are creating their concepts through CAD tools, and the entirety is compiled through DMU for the sake of evaluation. These virtual models are also used as mediators in various workgroups across the pre-study. For instance, meaning that maintainability and variability, i.e. important aftermarket aspects have the potential of being understood and discussed through this class of tools. These tools also provide opportunities for development of methods, suiting specialised analyses on issues subject to aftermarket interest, e.g. disassembly/assembly analysis, all for the purpose of evaluating and influencing in the most efficient direction.

The full potential of these tools is however not made use of in the eyes of aftermarket. Many of the analyses needed did not have a corresponding method implemented. Examples of useful methods for aftermarket are such that enables comparison between technical concepts, supportability, clash analysis when assemble or disassemble, and automation of analyses when having several product variants. The rationale behind this backlog is of course a slight portion of tardiness, but in addition, a low degree of knowledge of these kinds of tools amongst aftermarket engineers. Traditionally, being a skilled aftermarket engineer normally requires many, many years of experience from the in-service phase of the referred type of products. From the conducted study, it has been experienced that this type of excellence is rarely combined with the skilfulness in running CAD and DMU tools, which has turned out to be a showstopper for being considered in the product development community. Mediating viewpoints through digital models is not only sufficient as all intended receivers uses them. It also speeds up the process of contributing with aftermarket viewpoints, which is a necessity given the high pace of development. In order to better evaluate and influence product concepts, aftermarket engineers will need to increase their proficiency in using CAD and DMU tools. The work of Di Gironimo et al. [4] shows that it is possible to effectively work with these tools in the aftermarket development domain. The aftermarket engineers' ability to use, visualise and demonstrate problem issues through these tools affects their impact onto engineering. Short response times on raised cross-functional issues, e.g. aftermarket, do on the one hand increase the probability of receiving the wished attention by engineering, but do on the other hand also improve prerequisites for a more rapid development pace.

All these conditions, opaque methodology in product development work groups, unaccustomedness to product development and IT tools amongst aftermarket engineers, and in addition a high level of conceptuality in early phases, have diminished the outcome of the invested effort of the aftermarket pre-study.

5 Summary and conclusions

The main problem with design for aftermarket can be divided into three categories. Organisational issues which include the difficulties in cross-functional development and integration therein. The second category is related to the requirement management process and how concepts are created. The problem lies in defining proper requirements and then realising these through concepts that shows the best possible solution for the requirements regarded. The third category involves tools and software used by developers. Major problem areas are knowledge and lack of experience, as well as finding the proper tool with enough support for the tasks to solve and the process to work in.

The pre-study that has been subject to study has basically sourced from a mature organisation producing relatively stable and long-lived products. The cross-functional approach observed has however, on the whole, constituted a new phenomenon for the regarded organisation. The difficulties in finding an organisational setting that both satisfies the parallel pre-studies' need for independence in terms of delivering technical solutions, but also facilitates interfaces for cooperation on different levels has been shown obvious. Considerations of cross-functional aspects in product development need care on several layers in a project. Cross-functional viewpoints, such as aftermarket, need to be distributed on all levels where design-decisions are taken, to ensure wished product performance.

Systems Engineering is a valuable approach in efficiently utilising and coordinating the manpower of a large number of designers and cross-functional engineers in product development activities. It does however require a coordination of various actors' achievements at several phases. Stakeholders need to coordinate their efforts at very early stages, thus delivering coherent, and not redundant or unnecessarily dependable development prerequisites. The context of these efforts needs also to be transferred when the development task is handed over to product development. The embedded complexity in a cross-functional product development organisation needs to be bridged by an extensive and ¨thorough communication between the engineering disciplines. An enabler for better communication is design methods that presuppose cross-functional participation from an early stage, thus preventing concepts to evolve too much before being adjusted to e.g. aftermarket needs.

The condensed conclusions of this study are:

- A well-founded pre-study organisation and cross-functional interfaces therein, is of large importance to make certain that important features in the product design are taken care of.
- The way of working with requirements engineering need to be premeditated all along a pre-study, i.e. already from the beginning when specifying development, to secure that trade-offs are done early. It touches upon avoiding redundancies and needless dependabilities in requirements areas.
- Cross-functions, such as aftermarket, need to get more involved, and also earlier in concept development. Also methods for generation, evaluation, refinement and choice of concepts need to be further adapted to incorporate these aspects.
- The use of engineering tools, i.e. RM, CAD, and DMU, in engineering contexts is essential for cross-functional communication and understanding. Simply speaking,

cross-functional engineers need to speak to language of engineering when working in their fora.

7 Future work

An assessment of feasible requirements structures and related solution structures with respect to the aftermarket support system is a candidate for subsequent research.

Evaluation and adaptation of engineering methods for better aftermarket impact is another candidate for further work. Such an effort could also entail an adaptation of PLM tools and related methods in order to find better ways of analyzing and influencing design work.

It is also an option to further describe and/or prescribe the function of cross-functional design work groups.

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