Considering Assembly Requirement Specifications in Product Development: Identification and Approach

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ABSTRACT

Due to the major advantages such as reduced time to market and improved quality at lowered cost, the principles of design for assembly capabilities and concurrent engineering are of great significance when developing new products. However, identifying assembly requirement specifications and considering them in New Product Development (NPD) in a timely manner, while securing efficiency and robustness of assembly processes, still remains a challenging task. In presenting a case study of an NPD project in a manufacturing company, this article focuses on the process of capturing and incorporating the requirements related to the assembly system during the early phases of NPD. Further, the results of the research study indicate the different assembly requirements in the case company and pinpoint the challenges in practices involved in handling them. The assembly requirements identified in this research reflect some of the challenges encountered in handling the requirements, through the investigated requirement practice. Based on the results, the issues of when and how to consider the assembly requirements are highlighted in the conclusions and suggestions for future research are made.

1. INTRODUCTION

The fierce competition in today's market calls for new products that can be developed in shorter time and promise a lower cost of development while maintaining all the relevant quality measures. The essence of this highly competitive environment is to have all customers' needs and expectations at the heart of New Product Development (NPD) activities.

The first step towards product realization is product definition, a poor product definition being a factor in 80% of all time-to-market delays [1]. Unclear understanding and inaccurate assumptions of customer requirements have significant negative implications for design and manufacturing of a product in terms of quality, lead time, and cost [2]. To satisfy external and internal customers' needs and requirements, Requirements Management approaches have been applied in product development activities. An essential part of the requirements on NPD are the requirements related to the manufacturing and assembly system. In the development of mechanical products, where the geometries of the parts of the product largely influence the functionality of the final product [3], requirements related to assembly and manufacturing become of crucial importance and need to be considered as early as possible in the design cycle [4]. In order to develop products in line with the capabilities of assembly processes, the well-established Design for Assembly (DFA) methodologies [4, 5] have been used by manufacturing companies for more than three decades and have greatly contributed to reduced time-to-market and improved quality at lower cost. At the same time, these methodologies are considered as general reactive evaluation approaches directed more towards the completed design [6, 7]. To produce a vivid image of the final product, establishing a shared and clear knowledge around the requirements, in the early phases, is of a major significance. However, creating such a common understanding of the requirements in NPD between different stakeholders, including manufacturing and assembly, is still a challenging task in industry which leads to further ambiguities in the development process [2, 8]. Additionally and in spite of numerous approaches to the management of requirements in the literature, there are still apparent discrepancies between practical development activities and the prescribed procedures in the literature [9]. Moreover, there is a relative lack of empirical research into requirement practices in product development projects with a sharper focus on requirements related to the assembly system. To fill the existing gap in the literature through practical findings from the industry and supported by an

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extensive review of the previous research, this paper conducted a case study in a heavy vehicle component manufacturing company. The present paper investigates the practice of capturing and incorporating the assembly requirements specification during the early phases (planning and concept development) of NPD. The research results identify different types of the requirements related to the assembly system and highlight the challenges connected to the requirement practices taken in the case project. The conclusions show that the assembly requirements identified in this research reflect some of the challenges encountered in handling the requirements through the requirement practice investigated. Additionally, the issues of when and how to consider the assembly requirements are highlighted on the basis of the research results.The paper is structured as follows. Section 2 offers a review of the literature. Section 3 describes the research methodology used in performing this work. The results and discussions are provided in Section 4. The conclusions of the research paper and the suggestions for future research are presented in Section 5.

2. LITERATURE REVIEW

Throughout the process of product design and development, creating a precise product definition is of paramount importance. A large number of extensive studies carried out concerning the success factors and the best practices of product development, have pointed out the significance of the early phases of product innovation (including e.g. the opportunity identification, idea generation and product definition phases) and the careful assessment of market and customer needs for the success of product development [10]. Ulrich and Eppinger [11] introduced six phases of the generic product developments as; planning, concept development, system level design, detail design, testing and refinement and finally production ramp-up. Defining design specifications is an important process in a new product development project since the specifications largely affect the downstream product development activities [12]. Hence, establishing the requirements is critical in the design process, and therefore a central issue in design research [13]. However in practice, identifying various customer requirements and embedding them in the product image created is considered a daunting challenge. Understanding and fulfilling each individual customer's requirements has been recognized as a pressing challenge for companies across industry. It has significant negative implications on design and manufacturing of product in terms of quality, lead time, and cost [2]. According to Jiao and Tseng [14] the definition of a product is usually represented by a list of requirements, also known as product specifications or target values. They regarded product definition as a tedious, time-consuming and error-prone effort enacted process between customers, marketers, and designers.

Requirements management techniques, which initially were developed to tackle the challenge of product development in software engineering, have become widely used in the development of engineered mechanical products as well. The use of these methods enhances the quality of products and introduces procedures more structured than the widespread ad-hoc approaches applied in product development and concurrent engineering processes [2, 3, 14]. There are different perspectives on categorizations of requirements management activities in literature. For instance, Nuseibeh and Easterbrook [15] categorized the core requirement engineering activities in software development process as; eliciting, modeling and analysis, communicating, agreeing and evolving requirements. According to [2] there are three main tasks in customer requirements management; requirement elicitation, requirement analysis and requirement specification. Darlington and Culley [16] drew a distinction between the natures of engineering design requirements and software engineering requirements. Based on their work, requirement process in engineering design differs mainly from software engineering in the requirement specification stage. The evolution of product requirements in engineering design often stops on arrival at a complete, concise and correct description of the design need in the complete product, while in software engineering the development process does not stop at completion of the full design requirement. Some difficulties in managing requirements in the product development process have been identified and discussed in the literature [2, 9, 17, 18].

The Concurrent Engineering (CE) concept emphasizes the development of products and processes in a parallel manner. CE dictates the incorporation of production considerations in the early stages of product design [19]. Among all the proposed methods for capturing the needs of the market and of the engineering, translating them into requirements and then generating technical product specifications, the Quality Functional Deployment (QFD) technique developed in Japanese industry in 1970's, still counts as a popular approach [1, 20, 21]. QFD is a technique used to implement Concurrent Engineering [22], but certain limitations in QFD directed further research to develop additional empowering features for it also (see e.g. [23, 24]). In developing a new product idea, manufacturing and assembly requirements represent the extent to which the other expectations, requirements and specifications on the product are achievable. The absence of early involvement of manufacturing engineers and their interaction with the product designer or product design team has two primary results; unreliable products and late market release [20]. Geometry is created by manufacturing processes. A significant barrier to innovations in manufacturing is a lack of clarity over what is required of the product by the customer, as distinct from what has been designed into the product to meet the needs of

a specific manufacturing process [3]. Thus the process of embedding manufacturing and assembly requirements in product design becomes an iterative process. Pullan, Bhasi [19] depicted a spiral design process to show that Concurrent Engineering and Design for Manufacturing are accomplished through an iterative design process in which marketing experts, designers, manufacturing engineers, and other personnel jump back and forth between identification of customer needs, design of the product and assessment of manufacturing issues. However, handling assembly requirements through requirement practices in concurrent product development has not been addressed explicitly in the literature. To provide an insight into the requirements related to the assembly system, as a crucial part of a product's requirements, and to pinpoint the related challenges in practice, this paper investigates the requirement practices in an NPD project with a specific focus on the assembly requirements, during the early phases of development.

3. RESEARCH METHOD

The findings of this paper are based on an extensive literature review and have been obtained by conducting an exploratory single case study in a heavy vehicle component manufacturing company which develops and produces components for heavy vehicles. Case study is the preferred research method to closely investigate a phenomenon within its natural context [25]. The chosen unit of analysis in this case study is the approach towards assembly requirements in an NPD project in which one component platform for three different types of heavy vehicles was developed. The requirements referred to as "assembly requirements" in this research, include all the requirements in the NPD project which are related to the assembly system, regardless of whether they were defined by the assembly team or other stakeholders. The under-study NPD project (designated NCPD-New Component Platform Development, in the following.) started in 2008 and completed the concept development phase by the end of 2012. This research paper has concentrated on NCPD project during the time period between the project's initiation and the end of the concept development phase. It should be noted that the assembly lines in the case company are product-dedicated lines in which different variants of each product are assembled. The final assembly tasks are mainly run by the operators with the assistance of tools and equipment. The NCPD project has been selected for this case study, primarily, for two main reasons. Firstly, the NPD project in the case company was a platform project for three different products, being unique in terms of project scope and size as a result of implementing a new strategy in the case company. The new strategy aimed at higher quality of the product, improved fuel efficiency, competitive cost reduction, performance excellence and optimized aftermarket profitability. Secondly, and owing to the changes in the technology applied in this project, the resulting product was expected to have a totally new content which can later cause complexity in assembly processes. Additionally, throughout this project, set based concurrent engineering approaches accompanied by lean product development principles were applied in the company. At the time of conducting this research, the NCPD project was referred to as a master project in terms of its collection of requirements (including assembly requirements) for use in future NPD projects. During a four-month period; observations, study of project archival records and documents in addition to fourteen interviews with the project team members were the main means of data collection. The interviews were designed as semi-structured interviews and were conducted with both the project manager and the other project members in the assembly, product design and system engineering teams. All the interviews were recorded and most of them (57%) were transcribed. The length of the interviews ranged from 46 minutes to 169 minutes. In addition, the active involvement of one of the authors as the production project manager for the NCPD project provided a deep insight into the project and full access to the project documentation. The knowledge acquired from a review of the previous research in requirements management, product development and concurrent engineering facilitated the design of the interview guides and the analysis of the data. The analysis of data has been carried out during and after the process of data collection as suggested by Merriam [26]. Measures have been taken to ensure the validity and reliability [25, 26] of the research by taking a systematic approach and triangulating, during the data collection and data analysis. Finally, to verify the results obtained, the findings of this study have been discussed with the case company.

4. CASE STUDY RESULTS

4.1. CONSIDERING ASSEMBLY REQUIREMENTS IN EARLY DEVELOPMENT PHASES

The process of managing requirements in the NCPD project began as a learning experience for the case company in terms of applying requirement practices within product development activities through a methodical approach. Except for the company's general guidelines for system engineering and requirement practices, no established and systematic procedure has been in place in the case project. Prior to the NCPD project, requirements collected during the lifecycle of each NPD project were not handled by means of requirements management techniques. The product platform

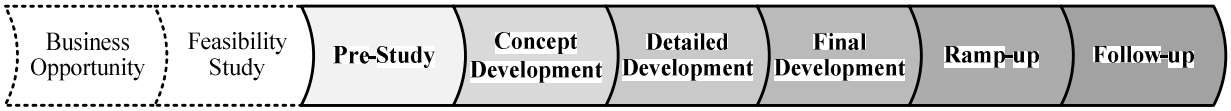

Figure 1. Development process in the case company in which the first two phases belong to product planning.

development team was responsible for the requirement practices. The actions linked to the requirements were commenced during the feasibility phase and continued regularly until the end of the concept stage. Figure 1, shows the different stages of product development process for the NCPD project in the case company. The requirements were expected to be frozen at the end of the concept development stage to be used in the detailed development phase. In order to provide enough insight into the status of the assembly requirements, as one of the key stakeholders of the product, the applied requirement practices in the project were first investigated and illustrated, see Figure 2. The working process began during the feasibility phase by identifying the stakeholders from different disciplines in the company; aftermarket, operation (assembly, fabrication), verification and validation, product planning, and platform technologies. Since the component in the NCPD project was developed to be used in three different products, in addition to the stakeholder responsible for the assembly of the component, three stakeholders responsible for the assembly of the complete vehicle products were also among the participants. Each stakeholder appointed their representative to take part in the project meetings. It is worth mentioning that assembly team also anchored the internal logistics needs and requirements. Requirement practices in the NCPD were iterative during feasibility, pre-study and concept phases. As illustrated in Figure 2, different meetings were held during the early development phases to support the requirements management process. At the beginning, eliciting the needs and primary requirements for all the stakeholders in a textual format was performed. Following the individual discussions with each stakeholder, all the requirements elicited were discussed by the project team (all the stakeholders and the project manager) on a weekly basis. At the same time, verification tasks were assigned to those requirements to which the project team committed and consequently, the list of refined requirements was updated. In addition, during individual meetings with each stakeholder, the project manager prioritized the elicited requirements .The priority level used for the requirements comprised of three levels; “must-be”, “should-be” and “optional” . “Must-be” requirements were those the absence of which would jeopardize the continuance of the project, e.g. the legal and environmental requirements. “Should-be” requirements added value to the project and it was for the project steering committee to decide on their existence. Finally, the, “optional” requirements, were those agreed upon according to the added value they might bring to the stakeholders and the project. At the end of each project phase, the project manager and the stakeholder’s managers approved the refined requirements for that certain gate and reported them to the project steering committee for further approval. All the requirements, were kept, updated and followed through Excel software.

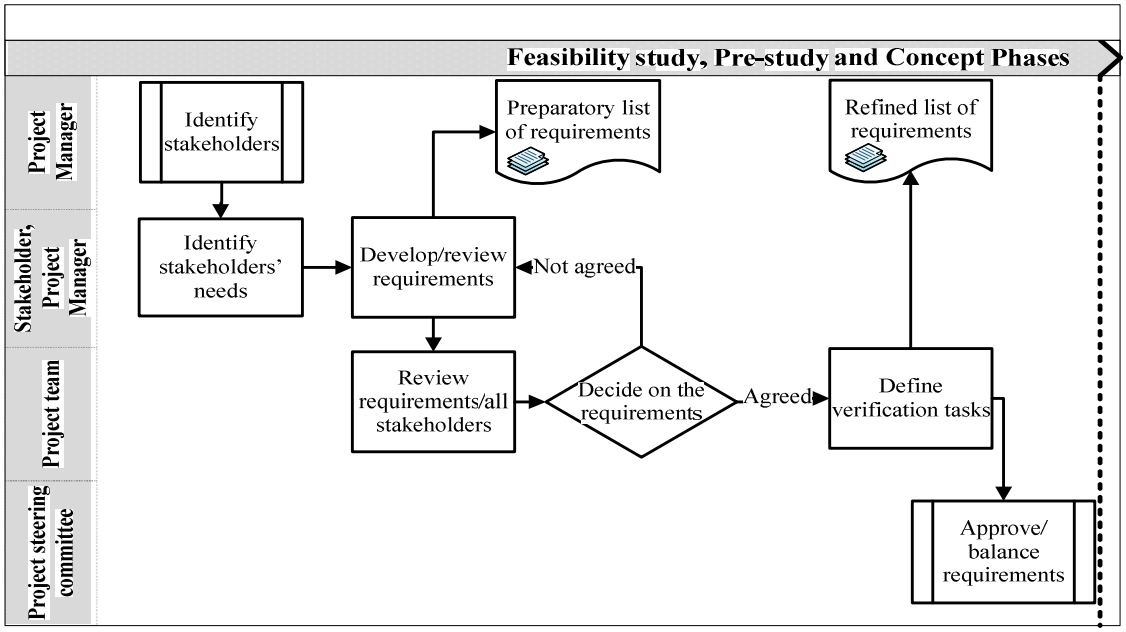

Figure 2. Practice of considering assembly requirements in early development stages in the case project.

4.2. Assembly Requirements, Types and Clustering

The assembly requirements defined, either by the assembly team or the other stakeholders in the case project, have been identified, see Figure 3. The categorization has been based on the existing strategic areas in the case company. These requirements are a collection of all the assembly requirements proposed in the case project until the end of the concept development phase; in the "refined list of requirements" and the "preparatory list of requirements" as illustrated in Figure 2. At the end of the concept development gate when the requirements were to be finally approved for use in the detailed development phase, some of the requirements as marked with (P) in Figure 3, still remained unapproved by the team in the "preparatory list of requirements". In addition, it seems that not all of the approved assembly requirements in the early development phase are defined according to the same level of details. For instance, the requirement "All molded O-ring shall have a tang" has been defined at a more detailed level than the system level; the component product as a whole. The similar pattern in defining the requirements at the different system levels is also observed in the not approved requirements (P), (e.g. fixtures shall be used if tightening torque is >X Nm). Moreover, some of the requirements presented are requirements that are based on the assembly processes (e.g. number of unplanned stops and product replacements) while others appear to be more driven by product physical properties in the assembly processes (e.g. maximum product weight shall be <X kg) .

4.3. Challenges of Considering Assembly Requirements in Early Development Phases

The challenges in considering the requirements related to the assembly system, during the early phases (planning and concept development) of NPD, were connected to the procedure of requirement practices and the socio-organizational factors needed to facilitate handling of the requirements. These challenges are shown in Figure 4.

4.3.1. Socio-Organizational Factors

Challenges concerning the socio-organizational factors are categorized as communication, involvement in requirement practices and general knowledge of the requirement practices.

Communication

The lack of direct communication between the stakeholder of component assembly with the other stakeholders, especially those responsible for the assembly of the final products, led to ambiguity in identifying needs and consequently the assembly requirements. Poor communication was a cause of conflicts between the requirements raised by the assembly team and those of the other stakeholders. The issue became problematic especially when it became necessary to resolve these conflicts and make trade-offs. In addition, since representative on behalf of each stakeholder participated in the requirement practices, the opportunities to develop a direct and firm communication with the management level for further clear decision-makings were missed. Although the lack of communication acted as a barrier for the requirement practices, the whole process of requirements management itself is meant to provide a

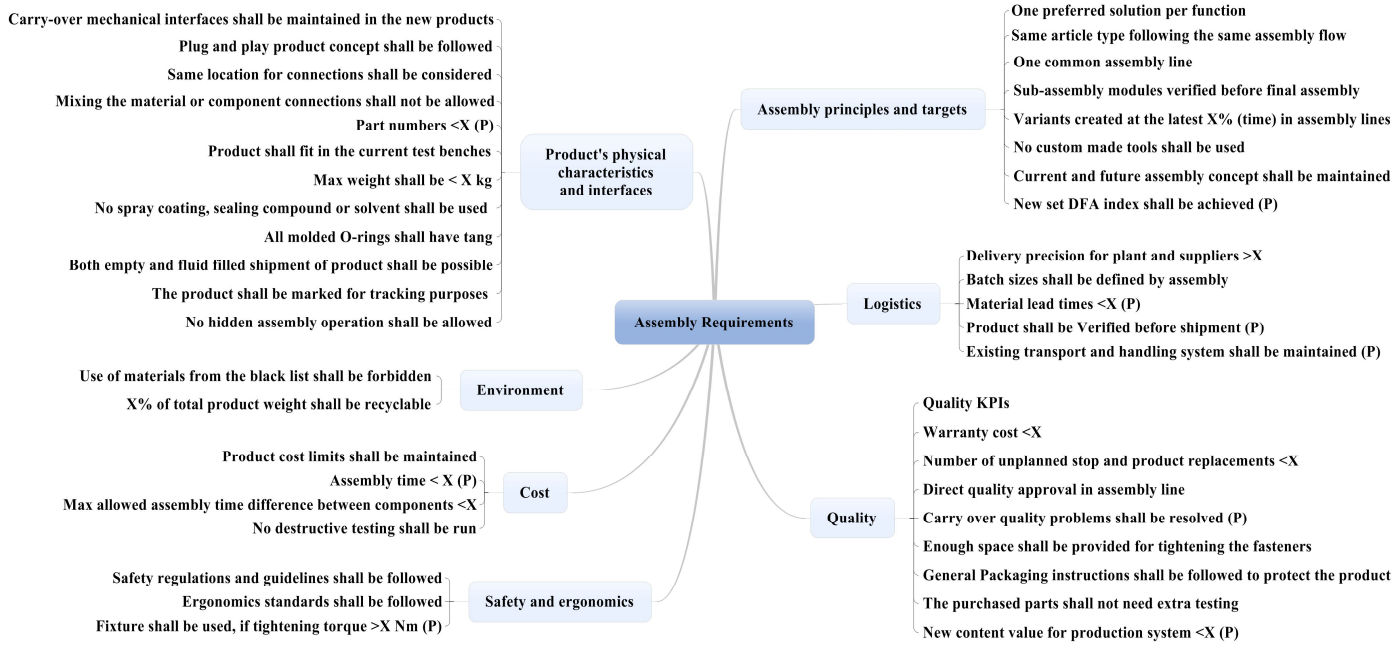

Figure 3. Clustering of assembly requirements for the component product in the case project.

platform to establish prevalent ideas and a common understanding between the assembly and the product teams. *"Requirement practices are actually very fruitful as they lead to constructing shared views among product team and the other stakeholders"* one respondent stated.

Involvement in requirement practices

Although a cross-functional team existed, the requirement activities were mainly managed by a small team from product development. The other stakeholders such as assembly were not equally involved during the whole process. This small team shouldered the whole responsibility irrespective of their lack of holistic insight into the other project's disciplines. Additionally, as the volume of requirement activities decreased later in the project, the resources assigned to the requirement practices were released to continue working in their own special fields. This resulted in dissipation in leading requirement activities afterwards. *According to a respondent "although the requirement practices are not well taken care of at the later stages of development, they should be integrated in our daily works since they create awareness of the upcoming challenges in the development process".* Moreover, closer involvement of the system engineering team was expected to support the assembly and other stakeholders in orchestrating the whole process.

General knowledge of requirement practices

Limited knowledge of requirement practices within the assembly team and other stakeholders was a key obstacle that hindered and complicated fulfillment of the requirement activities in the project. Despite the existing general system engineering guidelines and training, this problem was caused by a lack of expertise, throughout the whole organization, in working with requirements techniques. This eventually led to different perspectives, assumptions and understandings regarding assembly requirements and how they should be written.

4.3.2. PROCEDURAL FACTORS

Identification and record of requirements

In addition to the common dissimilar perceptions of the assembly requirements between product development and other stakeholders, the assembly team had a natural tendency to define the limitations of assembly processes whereas the project team was more interested in product related requirements in the assembly processes (e.g. dimension and weight) which do not necessarily require a description of the assembly process itself. Moreover, some of the assembly requirements identified were more relevant at the product (component) level than in connection with the product subsystems or even the larger system; the final vehicle. This was partly due to the fact that the system and subsystems were not clearly defined at the early stages of the project. Taking that into account and considering the fact that assembly requirements were captured in the early stages of the project, it became difficult to either decide on the requirements to be developed later for the subsystems or to forecast the forthcoming assembly requirements in the future. Considering the dynamic nature of the production and assembly systems, the requirements management process should enable updating of the assembly requirements according to the changes occurring throughout the later stages of a project lifecycle. Some of the requirements were never recorded or updated as they were tacit requirements in designers' minds, discussed during the design review meetings with assembly team, or randomly introduced during the project lifecycle. Moreover, the traceability of the needs to the requirements and the interfaces among assembly requirements and other stakeholders' requirements were rather vague, particularly as some of these assembly requirements were actually suggested by stakeholders other than the assembly team itself.

Prioritization of requirements

On the whole, the prioritization method and the criteria established to categorize each requirement according to its priority appeared to be barely adequate. Moreover, the prioritization approach was to a great extent dependent on the personal judgment and was difficult to evaluate. This led to the creation of two different priority levels for the assembly requirements, one arranged by the product development team for assembly requirements and recorded in official project requirements list and the other used internally by the stakeholder for their proposed assembly requirements. Unclear criteria for requirements priority increased the tendency within the project team to categorize a great number

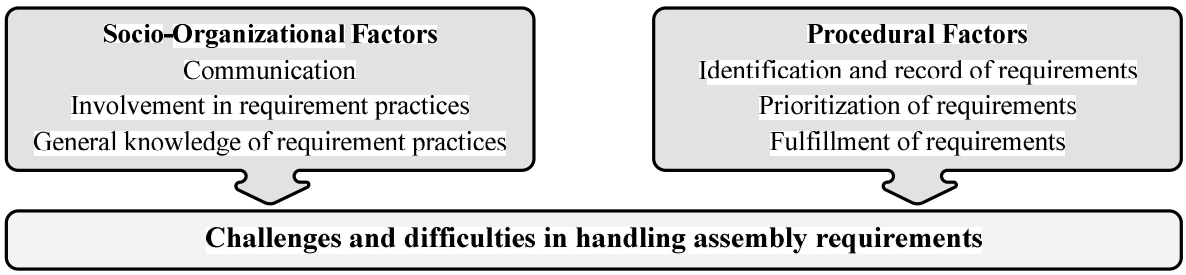

Figure 4. Recognized challenges in handling assembly requirements.

of requirements as "must-be" and "should-be" requirements which later proved to belong to the lowest level of optional requirements.

Fulfillment of requirements

At the beginning of the project and at the time the requirements were identified, the assembly requirements were rather subjective. This made definition of verification activities a rather challenging task. Later, when the time was appropriate to evaluate fulfillment of the assembly requirements, the main focus was on the functionality and the design of the product to the extent that the requirements were occasionally changed to suit the developed product concept.

Some of the challenges identified in acquiring assembly requirements in the case company can be interpreted as the common intrinsic difficulties experienced in requirement practices. In addition, the absence of a clear and effective working process in the early phases of the project added to the ambiguity created around the whole process. Moreover, the roles and responsibilities of those involved in performing the relevant activities were not fixed or clearly defined which resulted in uncertain commitment to the requirement activities. Despite the fact that design for assembly and design for manufacturing guidelines existed in the case company, they were more referred to as general guidelines that designers needed to acknowledge rather than to follow explicitly when developing assembly requirement in NPD. Furthermore, although a number of specialist requirements management software units for handling requirements were available, the project team considered them impractical and eventually selected Excel as this was easily learned by all the project members and could be used effectively for structuring and maintaining the requirements.

5. CONCLUSIONS , LIMITATIONS AND FUTURE RESEARCH

The practice of handling assembly requirements in a new product development project within a case company was investigated and illustrated in this paper. In the process investigated, the focus was on two main tasks of requirements management; the elicitation and analysis [2] of the requirements related to the assembly system. A number of different assembly requirements proposed by different stakeholders, during the early stages of product development process; planning and concept development [11] in the case company have been identified and categorized. The categorization of the assembly requirements indicated the different strategic areas that could contribute to the elicitation of the requirements related to the assembly system in the case NPD project. Based on the presented requirement practice, a number of challenges faced by the assembly team and other stakeholders during the requirement managing process were pinpointed. The challenges and difficulties were divided into two groups of socio-organizational and procedural factors. Some of the challenges in handling assembly requirements identified, were in line with the general difficulties in the process of requirements management in the previous literature [2, 9, 17, 18]. However, in this paper the primarily focus has remained on the assembly requirements appearing during the early phases of development process. The assembly requirements identified in this research reflect some of the indicated challenges faced in handling the requirements through the presented requirement practice. The assembly requirements appeared to apply at different levels of detail although they were all captured during the early phases of development. This made some of these requirements unusable in the early development phases as the requirements were related to a level of detail not yet considered in the initial NPD phases. In addition, some of the assembly requirements were oriented towards assembly processes while others were related more closely to product properties. The different orientation led to a difficult decision-making process to include these requirements in an NPD requirements inventory.

This highlights a need to consider the requirement practices during the whole development process rather than only as focused activities during the early development phases. Therefore, a clear integrated working process with a concurrent engineering approach is needed to capture assembly requirements at different stages of NPD by means of addressing the challenges mentioned in this research. This calls for further research to identify the types of assembly requirements that need to be continuously recognized during each specific development phase to minimize the effects of challenges and to prepare for an improved product definition. Being based on a single case study in one manufacturing company, this paper does not claim to cover all the challenges encountered in developing the different types of assembly requirements of NPD projects. It provides, however an interesting insight into areas requiring consideration when developing assembly requirements in manufacturing companies. A sound solution requires the adoption of an effective working procedure and clearly defined expectations of assembly requirements during the different phases of NPD.

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