Strategy for using Prototypes in the Product Development Process

Master of Science Thesis

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ABSTRACT

The product development is a complicated process for many companies, especially for Saab EDS which has complex and high technology products. Because of this, Saab EDS is searching for opportunities to increase the efficiency of the product development process. One method[1] to achieve this is by a more frequent use of prototypes in combination with a clear strategy for prototyping and the usage of a prototyping process.

The purpose of this master thesis is to map the existing usage of prototypes and classifications. In addition a part of the purpose will be to investigate how a more optimised usage of prototypes can affect the efficiency of the product development process. Generally, in present situation the classification can be seen that prototypes is used as an overall expression that containing mock-ups, functional models (FUM) and prototypes. Below in figure 1 is the division visualised in order to provide the reader a brief overview.

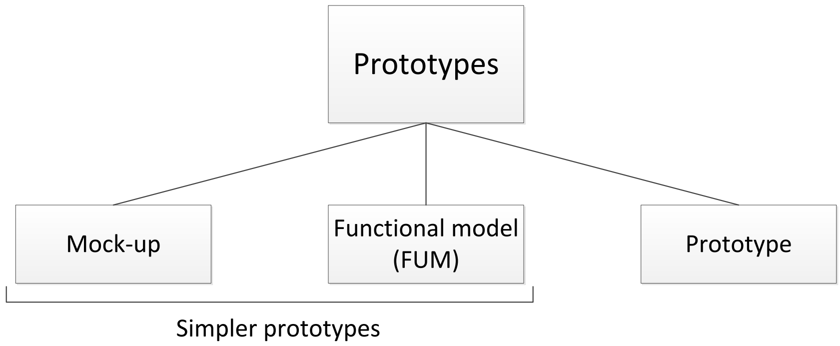

FIGURE 1 PRESENT CLASSIFICATIONS OF PROTOTYPES AT SAAB EDS IN GOTHENBURG

In order to map the existing usage of prototyping at Saab EDS, a case study method was used to work with all relevant empirical data and comparing it with statements written in relevant literature. The literature in combination with the empirical findings was merged together and analysed in order to explain certain phenomenon found within the organisation and to provide useful recommendations.

The result provided to Saab EDS is a prototyping process that can be used in combination with the existing product development process. To ease the use of the prototyping process several supporting documents has been compiled. The prototyping process is developed to increase the usage of different prototypes and to provide a uniform working method. A new prototyping classification has also been suggested which aims at providing a unified definition of different prototypes.

At Saab EDS there is a possibility of increasing the efficiency by a more optimised usage of different prototypes. By increasing the usage of mock-ups (simpler prototypes) many different benefits can be achieved such as improved communication between people and a reduction in the risk of late changes in the product development process. By using the prototypes in combination with the stage-gate process and project framework of the product development several benefits can be gained. Examples can be an easier visualised project progress and improved decision-making within the gates.

There is a strategy to follow for Saab EDS and the recommendation for the strategy will be to implement the prototyping process as a natural part of the product development process.

[1] The prototype is a tool itself and the prototyping process is seen as a method.

ACKNOWLEDGEMENT

This master thesis was made upon the request from the Mechanical department at Saab EDS in Gothenburg who has defined a need for an investigation regarding their usage of prototypes. It has been conducted within the Division of Operations Management at Chalmers University of Technology. This thesis is the final piece of two students' education within the master program of Product Development.

We would like to start with expressing our appreciation to our supervisor and examiner Lars Trygg, Associate Professor at Chalmers University of Technology. Your knowledge and expertise within the area has substantially contributed to the quality of the final result of this master thesis. The support in form of guidance and advices has been of great value throughout the master thesis.

Secondly, we would like to thank our supervisor Christian Sandberg, Sub-system responsible at Saab EDS in Gothenburg. This thesis work had been hard to conduct without your support and knowledge of the organisation at Saab. The continuous communication throughout the master thesis has been of great value in order to fulfil the needs stated by Saab EDS. In addition we would like to thank our manager at Verification & Services, Christel Lenz Augustsson for your support and believe in the project.

We would also like to express our appreciation to the steering group linked to our project, which has provided interesting discussions and feedback. It is also important to mention and be grateful to people in the organisation who has taken time to participate in meetings, interviews and other informal discussions that have contributed to provide useful information connected to the thesis.

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Christian Ankarbranth & Martin Mårtenson

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ABBREVIATION LIST

CAD = Computer Aided Design

DR = Design review

EDS = Electronic Defence Systems

FUM = Functional model

HRW = Hardware review

IFS = Industrial and Financial System

ILS = Integrated Logistics Support

MCD = Mechanics & Cable Design

MMI = Man/Machine Interface

PDM = Product Data Management

P-mode = Preliminary mode

R & D = Research and Development

R-mode = Release mode

RPD = Rapid Product Development

SD = Supporting document

STL = Stereolitography

TRW = Technical review

Keywords: Prototype, mock-up, functional model, prototyping process, product development process, strategy for using prototypes

1. INTRODUCTION

This chapter aims at providing the reader with a brief description of the company where this master thesis has been conducted. It also describes the purpose of this thesis and why this is interesting for the company and presents the research questions worked with throughout the thesis. Finally, the limitations of this work and the outline of the report are presented.

BACKGROUND

Saab AB is a multi-national company which serves the global market of governments, authorities and corporations with products, services and solutions ranging from military defence to civil security (Saabgroup, 2013). Saab AB has today approximately 13000 employees around the world and the sales 2012 was 24 billion SEK (Annual account). The company is divided into a number of different business areas such as Aeronautics, Dynamics and Electronic Defence systems.

This Master thesis is based upon the request of Saab Electronic Defence Systems (EDS) in Gothenburg which is one of the above mentioned business areas within Saab AB. Saab EDS is specialised within electronic warfare and radar systems and has a product portfolio covering airborne, land-based and naval radar but also electronic support measures and self-protection systems. Saab EDS has over 50 years of experience in electronic warfare and has delivered more than 300 radar units.

An important aid to the product development process is the usage of different kinds of prototypes[2]. If used in its right context it can increase the efficiency of the product development process (Bebb, 1991). Depending on where in the product development process the prototype is used, the level of complexity and comprehensiveness will vary, from simple to complex as the development progress. A prototype can be both physical and virtual with a large number of different definitions. By starting to use more physical prototypes throughout the design phase of the development process many problems can be reduced such as delays and rework later in the process. A prototype can aid the development process in many dimensions, examples can be that prototypes can provide an effective framework for communication and rapid learning. Within the range from simpler to more extensive prototypes the difference in cost will be substantial especially when the products are large and complex with high technology.

The product development process at Saab EDS is very extensive and takes long time due to highly complex and high-technological products that have comprehensive customer requirements. To meet these customer requirements Saab EDS needs to verify the product in several stages and some redesign is almost inevitable. Today there is a need within the company to increase the knowledge of how to build and work with different kinds of prototypes. At Saab today there exists no unified method of working with prototypes, instead each development and usage of a prototype is highly individual. Therefore the company has initiated this master thesis to investigate how the use of prototypes can be of greater aid in the product development process.

[2] A prototype is an early sample or model built to test a concept or process or to act as a thing to be replicated or learned from (Wikipedia, 2013).

PURPOSE

The purpose of this master thesis is to investigate how different kinds of prototypes are used at present situation at Saab EDS. It also includes eliciting what type of specific needs that is of importance from the usage of different prototypes throughout the development process. This will include conducting an analysis of the present situation at Saab EDS regarding how the different types of prototypes are used today and how the usage can affect the efficiency of the product development process.

There are many different definitions and classifications of prototypes which can create confusion in the development process and in particularly when different departments communicate with each other. It will therefore be of interest to investigate which classification is used and what different definitions that are stated.

The delivery and recommendations to the company will be a prototyping process which can be used when developing prototypes. By the use of this process the aim is to increase the efficiency of the product development process.

The above mentioned purposes can be summarised in three research questions that are listed in the next section.

RESEARCH QUESTIONS

- How do Saab EDS work with prototypes and how are they classified in present situation?

- Is there a more appropriate prototype classification for Saab EDS to use?

- Is it possible to change the way of working with different kind of prototypes in order to increase the efficiency in the product development process?

DELIMITATIONS

The focus of this thesis work will be in the area of physical prototypes. The virtual prototypes and their effect on the product development process are not discussed. This since Saab EDS in Gothenburg wants to increase the usage of physical prototypes and that virtual prototypes are already used in great extent. Within the area of physical prototypes the extensive focus will be on Saabs needs from mock-ups, this since Saab has a desire to increase the usage of these simpler prototypes.

The recommendations for the usage of prototypes will be from the mechanical department's perspective. However, some recommendations will be regarding how prototypes can be used in cooperation with the project framework and consequently designed for the project management department. In addition the recommendations should be seen as an aid mainly when developing hardware, not software.

A number of factors will contribute to determine the cost and it will be difficult to make an appropriate cost estimation of different prototypes. Therefore this project will not have an extensive focus on different costs associated with prototypes.

OUTLINE

SECTION 1 presents an introduction and background to both the actual subject and the company.

SECTION 2 describes how the work has been conducted and what methods that has been used throughout the project.

SECTION 3 presents relevant literature connected to the subject and this chapter is used as a frame of reference to the subject.

SECTION 4 lists the empirical findings that have been conducted from mapping of the current situation at Saab and from different interviews made both internally and externally.

SECTION 5 presents an analysis that has been made by comparing the empirical findings from section 4 with the frame of reference presented in section 3.

SECTION 6 provides the result delivered to Saab, in terms of a main prototype process and other documents that are designed to support the process.

Section 7 presents conclusions made from the analysis and is connected to the research questions which are linked to the overall purpose of the master thesis.

Section 8 presents a discussion which is mainly used to reflect over the conducted work, such as the suitability of used method and structure of work.

Section 9 provides recommendations to the company of how to proceed with the prototype development process and how it could be implemented to the existing product development process at Saab.

2. METHOD

This chapter describe the method used throughout this thesis work. It describes the case study method used and why this is suitable for this type of research. The different sources of information used and how the information was collected through interviews are also described.

The method used in this master thesis is based upon the methodology of a case study. This methodology is ideal for exploring new processes or behaviours that are little understood Meyer (2001) but also when there is a need for a holistic, in depth investigation (Feagin, Sjoberg, & Orum, 1991). The study is useful for answering the questions of *how* and *why* regarding a contemporary set of events (Meyer, 2001). There are three different approaches to design a case study and each approach is beneficial to use in different studies. The different approaches are explanatory, exploratory and descriptive case studies and these can be single or multiple-case studies (Tellis, 1997).

In an exploratory research, fieldwork and data collection can be conducted before the research question is properly defined and can reveal other phenomenon to be examined (Zainal , 2007). The descriptive case studies aim at explaining natural phenomenon which can occur within the data. The explanatory research on the other hand examines the entire data thoroughly in order to explain the data.

This master thesis will according to the above description use an exploratory approach in the beginning of the project when mapping the organisation and the needs at Saab EDS before finally deciding the research questions. When preceding the work analysing and explaining the different data gathered, the study will have more of an explanatory approach.

The case study methodology has four recommended stages (Yin, 1994):

1. Design the case study
2. Conduct the case study
3. Analyse the case study evidence
4. Develop the conclusions, recommendations and implications

These are the steps to conduct in order to have a successful case study and each step will be briefly summarised below.

DESIGN THE CASE STUDY

This stage is composed by two subareas: *determine the required skills* and *develop and review the protocol.* First it is important that the researcher possesses the necessary abilities for conducting a good interview in order to get usable data. Second the case study must be planned and accessibility and location of the data examined followed by preparation of the questions to be asked.

CONDUCT THE CASE STUDY

The second stage of the methodology is to *conduct the case study.* In this stage there are three tasks that need to be conducted for a successful project: *Preparation for data collection, Distribution of the questionnaire* and *Conducting interviews.* The focus of this stage is the activity of collecting data from the different sources (which will be discussed later in this section) chosen to provide the information.

ANALYSE THE CASE STUDY EVIDENCE

This stage in the methodology aims at summarising and analysing all the gathered information from the different sources. Certain aspects that the researcher must carefully review are for example: showing that all relevant evidence was used, that the analysis addresses the most significant aspect of the case study and that all rival explanations were used.

DEVELOP CONCLUSIONS, RECOMMENDATIONS AND IMPLICATIONS BASED ON THE EVIDENCE

The concluding activity of the case study is performed in this stage and is an important part of the methodology. This is where the result from the study is communicated to the potential user. It is important that the explanations and recommendations are easily understood in order to not fall into disuse.

SOURCES OF INFORMATION

There are a number of different sources of information to be used when collecting the necessary data. Yin (1994) identified six sources of information listed below; the sources with number 1-3 are used in this case study and further in detail explained how they were used.

1. Documentation
2. Interviews
3. Physical artefacts
4. Archival records
5. Participant observation
6. Direct observation

DOCUMENTATION

A number of sources have been used when collecting documented data and information and is presented below:

- *Literature*: Several different books, articles, thesis work and journals have been used throughout the project within the subject of prototyping. These have primarily been accessed through the Chalmers University of Technologies' library, but literature has also been found on the Internet by searching on Google. Examples of keywords that have been used searching for relevant literature are; "product development process", "prototyping process", "rapid prototyping", "physical prototypes" and "prototypes within product development".
- *Internal documents at Saab*: Internal Saab documents where studied through their internal PDM-system, IFS, but also through their internal website which provides an easily understood overview over processes and methods. Flow-charts, description over methods and documents providing information about the product development process are example of documents accessed and used.

INTERVIEWS

To get an understanding of how the organisation is working with prototyping today, a number of interviews were conducted. There are a number of different procedures available when conducting an interview depending on the purpose and the characteristic of the needed information. The interviews can be structured, semi-structured or unstructured, from which the semi-structured method was chosen (Karlsson, 2009). This method is also recommended by Yin (1994) when conducting a case study. The semi-structured interview provides questions that ensure certain areas being covered during the interview, but still with some freedom for the informant to speak freely. This is done by the use of for example open-ended questions which are designed to encourage the informant answering not only with yes or no.

In order to get a holistic view of the usage and opinion regarding prototyping, people from different departments within the company were interviewed. People from different departments such as market and product planning were interviewed, but also project managers and design engineers. The people interviewed were not only from different departments but also from different levels and with different responsibilities and authority. This in order to cover the whole range from division managers to design engineers which ensures that all different aspects is covered. Areas to be answered during the interviews were how they define a mock-up, what type of problems to be avoided with a more frequent use of mock-ups and how they would use it. Since the question was open-ended, answers given could sometimes be within areas not covered but still relevant for the topic and provide useful knowledge for the thesis work.

The interviews took place at Saab where the informant could feel confident with the environment. The time for the majority of the interviews was approximately 45-60 minutes. The questions were as mentioned above mostly open-ended in order to receive the informant's thoughts and more elaborated answers. The total number of internal informants was 16 people from different departments. A list of the internal people interviewed can be found in Appendix I and examples of questions used at the interviews can be found in Appendix II.

Besides conducting these formal interviews, a number of informal interviews were held with a number of different people from within the organisation. Informal interviews could be in the form of shorter meetings and conversations with people that could provide with information regarding for example working procedures.

A few meetings were held with a larger number of participants, for example was several workshops conducted. These meetings were valuable since getting people to discuss the concerned topic could elicit new information.

In addition to interviewing people within the organisation at Saab EDS a number of different external companies were interviewed. A list of the external people interviewed can be found in Appendix I. Since Saab EDS has not extensively worked with mock-ups it would be beneficial to search for information in other companies that has more experience of this. Two other companies within the Saab Group were interviewed, Saab Training Systems in Husqvarna and Saab EDS Jönköping. In addition one company from a different kind of industry were interviewed, Husqvarna Group AB. This was interesting in order to broaden the perspective with useful inputs from a company that might work with prototypes in a different manner due to different processes and products.

PHYSICAL ARTIFACTS

Different simpler prototypes that are previously used have been studied in order to find out for example what type of techniques that have been used and for what purpose. It was also beneficial to have these simpler prototypes to relate to in the interviews to find out advantages and disadvantages with the development and manufacturing of these items.

WORK FLOW

The work flow over how the above described method is applied is visualised in figure 2 below. It describes how the work has progressed throughout the project. It also shows the back feed both from the compilation of the interviews back to the theory and from the solution proposal back to the organisation at Saab. By having this later iteration and receiving feedback there is an increasing possibility of having a thesis project that will be valuable and fulfil the requirements from different stakeholders.

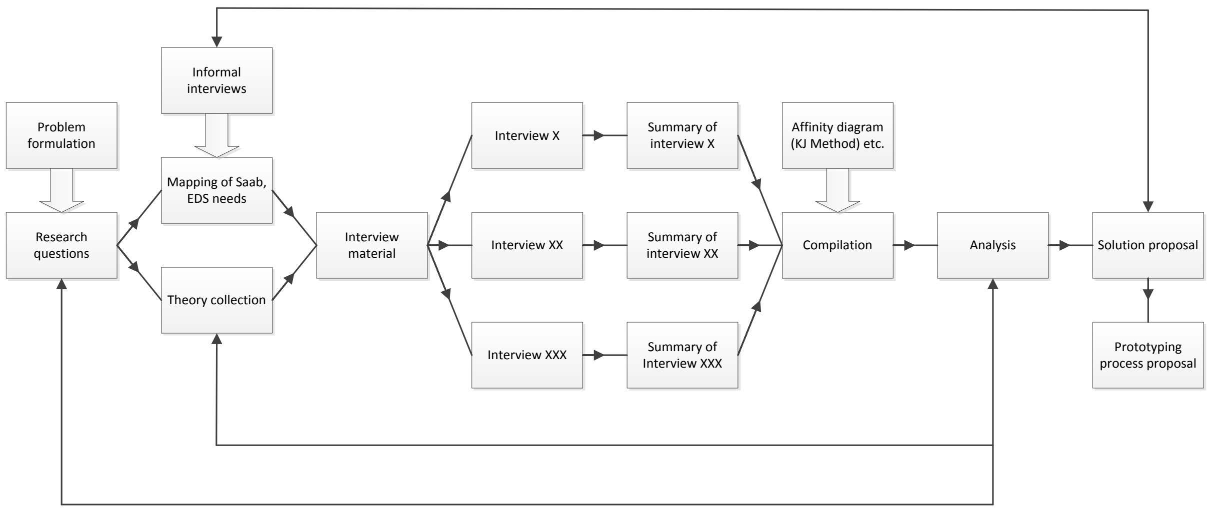

FIGURE 2 WORKFLOW PROCESS OF MASTER THESIS

The iteration back to receive feedback was in the form of conducting a workshop over the suggested process. The intention with the workshop was to receive different opinions regarding what was beneficial with the process and what parts needed to be changed. With the received feedback the process could be more tuned and adjusted to methods people prefer to work by. This step was highly valuable since it is difficult to create a process that is optimised from the beginning.

PROCESS MAPPING

A commonly used method when working with processes is the technique of process mapping. Process mapping is used both for incremental and radical change of existing processes and can be used both as an analytical tool and a process intervention (Kalman, 2002). A process map divides for example a manufacturing or service process into a series of individual steps, each step is not only labelled but also quantified in terms of personnel, time and resources required (Linton, 2007). There are several benefits listed with process mapping, examples of these can be that work flow is simplified and quality is improved (Kalman, 2002).

Besides the case study method there is a need for a method for working with processes. A mapping process is built upon several steps, Kalman (2002) suggests an eight step plan listed below:

- STEP 1: PRE-MAPPING
  Within the first step of process mapping the senior management identifies critical business or problem areas. It is important with the senior management's sponsorship and support throughout the mapping process in order for changes to be implemented successfully.

- STEP 2: CONSTRUCT A MACRO PROCESS MAP
  An overall view over the process is identified and provides an understanding of how work is done. This map should provide a common framework and a starting point for future work.

- STEP 3: IDENTIFY BOTTLENECKS AND PROBLEMS IN THE EXISTING PROCESS
  Different areas of problems and bottlenecks are identified on the macro map.

- STEP 4: PRIORITISE THE BOTTLENECKS AND PROBLEMS IN THE EXISTING PROCESS
  Some problems are not worth solving and the attention should be focused on the most serious problems. Problems can be prioritised based on (a) their likelihood of occur or (b) the consequence in case of error.

- STEP 5: CONSTRUCT A MICRO-MAP OF SELECTED SUB-PROCESSES AND IDENTIFY THE ROOT CAUSES OF THE PROBLEM
  In this step, the selected sub-processes are mapped and elaborated. It is important not to elaborate every sub-process to micro-level since this will be too time-consuming and a waste of time. These sub-processes should be connected to the selected problems or bottlenecks identified in step 4.

- STEP 6: REBUILD THE MAP
  Here the process is rebuilt to simplify and eliminate unnecessary steps and eliminate activities that add little or no value. It is important not to stop after the first iteration but to continue until the process has encountered a couple of iterations. The re-made process will then have a greater possibility of having as optimal design as possible.

- STEP 7: DEVELOP ACTION PLANS FOR MANAGEMENT APPROVAL
  In this step the rebuilt process is presented for the senior management for approval, discussion and support.

- STEP 8: IMPLEMENT THE PLAN
  The last step is about implementing the new process and for this to be successful it might require for example changed work policies and/or reward system. It is important that people working within the process find acceptance for the new method of working in order for it to be used as intended.

This method is worked with in parallel with the case study method. The above described method is used when identifying and developing the mock-up and development process. The case study method will be used on aspects regarding how information is to be handled and used in order to develop a process, taken into consideration both recommendations from literature and the specific circumstances and the organisation at Saab.

Bruijn, Heuvelhof, & Roel (2010) lists four core elements of process design visualised in figure 3, which will ensure a good process. The elements have the following rationale and classification according to the list below:

1. *Openness.* All parties with interest in the process design should have a possibility to participate in the decision making and the opportunity to highlight the issues they find interesting. The openness concerns both the choice of participants and the decision making process.

2. *Protection of core values.* All interested parties in the process have their own core values which they try to protect. It is important that the core values of each party are taken into consideration.
3. *Progress.* The two first elements do not exclusively ensure a good decision process. They can on the other hand contribute to that no good decision being made since everyone has different interest. This design principle addresses the need for the process to show sufficient progress.
4. *Substance.* Even if it is important that the interests of the different parties are protected, the decision making progress most proceed. The process should however also meet certain quality standards.

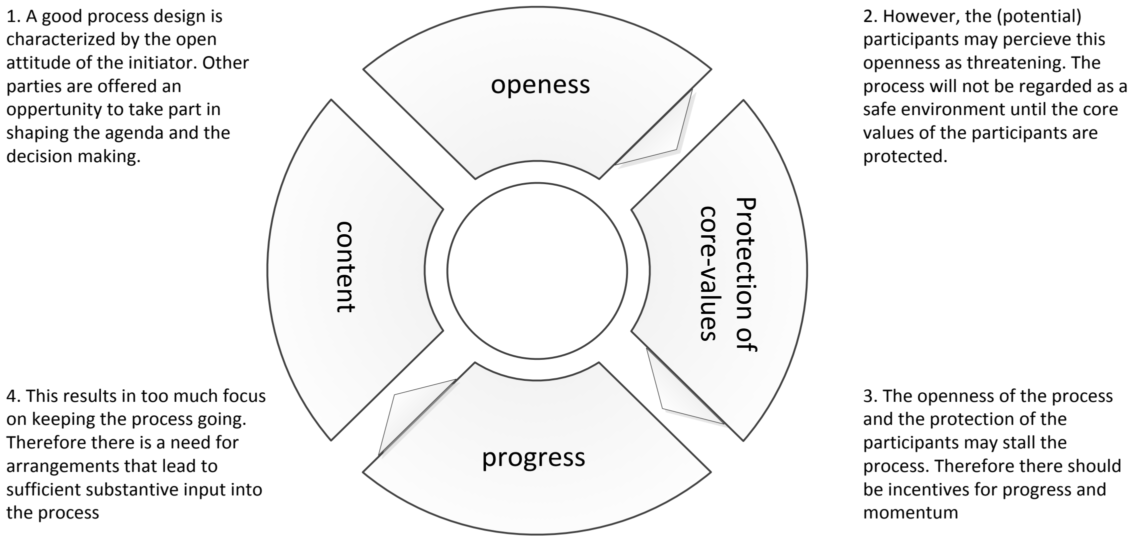

FIGURE 3 FOUR CORE ELEMENTS OF PROCESS DESIGN

3. FRAME OF REFERENCE

This chapter aims at describing the relevant literature for the subject. It will start with a description of what is written regarding product development and its implications. It continues with a description of prototypes and how the usage of these can affect the product development process. Theory regarding processes and changing behaviour is also presented.

DIFFICULTIES WITHIN PRODUCT DEVELOPMENT

In the competitive market which at present is intense, global and dynamic the development of new products and processes will be of high importance (Wheelwright & Clark, 1992). This in addition to decreasing product life-cycles and shortening of innovation cycles contributes to that the context become even more complex (Bullinger, Warschat, & Fisher, 2000). Companies that get their products to the market faster and more efficiently than their competitors will better satisfy the needs and expectations of their customers. By having a product development process that can provide this, an advantage will be gained over their competitors (Wheelwright & Clark, 1992).

The three particularly critical forces that are driving the development is listed by Wheelwright & Clark (1992) and accounted for below:

- *Intense international competition:* The numbers of companies able to compete with a high quality product has grown in every business. With the globalisation the international market has become more accessible and for example European companies have to compete with companies from Asia which today also delivers world-class products.

- *Fragmented, demanding markets:* Customers today are more sophisticated and demanding when purchasing goods and services. Needs that were satisfied unexpectedly yesterday is expected to be a standard today. Customers today seek products or services that provide solutions to their particular needs and problems.

- *Diverse and rapidly changing technologies:* The technology available for satisfying the needs of the customer has both a growing breadth and depth. Development of new technologies and deeper understanding of the existing ones will contribute to increase the variety of possible solutions available for engineers. In addition new technologies in areas such as electronics and materials can fundamentally change the character both for business and competition.

These forces will not only affect new companies in young markets but also affect mature industries where product life cycles where historically long. These forces will contribute to the challenges of product development listed by Eppinger & Ulrich (2012) which has the important characteristics of:

- *Trade-offs:* There is always trade-offs to be decided upon when developing a product. For example the necessity to make the product lighter by using a more lightweight material at the expense of the increasing material cost and consequently the price of the product.

- *Dynamics:* Technologies are constantly improving and customer demands are continuously changing. The demands of the customer might not be the same at the outset of the project as when the product is finalised.

- *Time-pressure:* Product development projects are almost always conducted during time-pressure. With a shorter time to market, the possibility to satisfy the customer will increase and the company will decrease the time to when the product will be profitable (Wheelwright & Clark, 1992).

- *Economics:* The process of developing, producing and marketing a new product is a substantial investment to a company. The resulting product must be appealing to the customer and relatively cheap to produce to achieve the return on investment for developing it.

PROCESS THEORY

In order to fully understand the prototyping- and its surrounding processes it will be beneficial to have an understanding about the theory, method and tools written regarding processes. By having a thorough understanding about the existing processes, its strengths and weaknesses, the process proposal will have a higher quality and be more applicable to Saabs organisation.

Ljungberg & Larsson (2001) defines a process as "a process is a repetitively used network of in order linked activities using information and resources to transform 'object in' to 'object out', from identification to satisfaction of the customer's need". A visualisation over this can be seen in figure 4 below.

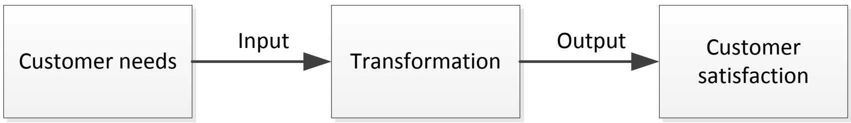

FIGURE 4 TRANSFORMATION PROCESS FROM CUSTOMER NEEDS TO CUSTOMER SATISFACTION

By using a proper definition it will be easier to identify and structure different existing processes within the organisation.

The process of an organisation can be divided into core processes and support processes (Slack, Chambers, & Johnston, 2010). The core processes can be seen as the operations that are adding value to the direct creation of product or services created by the company, e.g. the product development process. A support process can typically be Human Resources which is an example of a part of the organisation aiding the core processes.

A process includes a number of sub-processes and each sub-process consists of a number of activities. These activities can be further divided into tasks (Kalman, 2002). This type of division is visualised on the next page in figure 5.

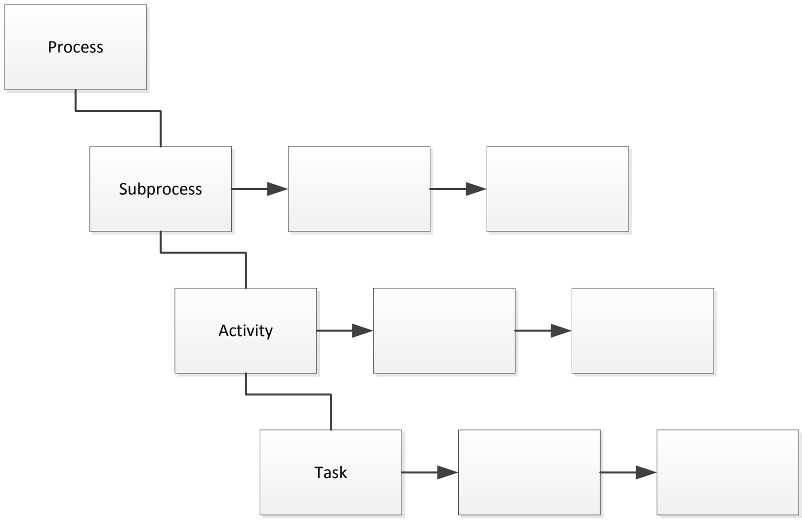

FIGURE 5 PROCESS DECOMPOSITION

A process approach brings discipline to how the work is done and helps build reliability to what is produced (Kalman, 2002). If the process is not in control and the output oscillates outside the acceptable performance, quality can be lowered and cost increase. If this should occur process mapping, described above in the method section, can be one method of identifying the causes of variability.

THE PRODUCT DEVELOPMENT PROCESS

New products often begin as ideas which evolve into marketing programs designed to meet the customers and other market stakeholders' needs and requirements (Thomas, 1993). The processes by which these products are developed are called the product development process. This process will have a different outline depending on which company that is studied. Different type of products and the environment where they are developed, will contribute to the individual design of the development process (Thomas, 1993). A product development process is defined as a sequence of steps or activities that an enterprise (a company) employs to design conceive and commercialise a product (Eppinger & Ulrich, 2012).

There are several ways to think about the product development process. One is that it gradually narrows down the initial ideas and concept in a rational way into a product that can be produced in a reliable and repeatable procedure by the production system (Eppinger & Ulrich, 2012). But it can also be seen as an information processing system where inputs such as customer requirements, corporate objectives and available technologies are transformed in the later stages. The process is considered complete when all information needed to support production and sales function is created and communicated (Eppinger & Ulrich, 2012).

Eppinger & Ulrich (2012) lists several benefits by using a formal product development process, they are listed below. A product development process that can be used when developing complex products is suggested by Eppinger & Ulrich (2012) and visualised in figure 6.

- *Quality assurance:* The phases and checkpoints specified by the process will contribute to increase the quality of the final product.

- *Coordination:* A clear and visual development process will act as a master plan aiding the different members of the team to know when and how they will contribute to the overall project. They will also know with whom and when to exchange material and information.

- *Planning:* A development process contains milestones connected to the finalising of each phase and the timing of these determines important progress within the process.

- *Management:* By using the development process in comparison with the on-going development effort conclusions can be taken by management regarding for example performance and possible problem areas.

- *Improvement:* With documentation and on-going review of the development process opportunities for improvements will be easier to detect.

As mentioned above the development process will have a different outline depending on which company that is studied, but the generic process will follow a certain outline that more or less has the same core steps. The steps below are listed by Eppinger & Ulrich (2012) and are part of a 6-step process.

Step 1: Planning

This phase precedes the project approval and launch of the actual product development process. Focus is on market objectives, corporate strategies and technology development. Sorli & Stokic (2009) includes involvement from the customers in this phase where the customers need should be mapped in close cooperation with the customer resulting in a product specification.

Step 2: Concept development

During the concept development phase a number of different concepts are generated and evaluated. A concept is a simpler description of the product where characteristics as form and functions can be evaluated. The focus here should be on working principles and not on details since a lasting and successful solution comes from the choice of the most appropriate principle and not from exaggerated concentration on details (Gebhardt, 2003). In the end of this phase one or more concepts should be chosen for continuous development. Thomas (1993) states that in order to have a successful concept development an on-going interaction with the customer needs to take place in order to refine the concepts. Sorli & Stokic (2009) states that there are two distinct paths to choose from when starting from the specified requirements: redesign or new design. A new design can be launching a radically new product with clear distinction from the old one while the redesign can be seen as developing a new product based on the old one by introducing a number of improvements.

Step 3: System-level design

This phase will include; definition of the product architecture, decomposition of the product into sub-systems and components and preliminary design of certain key components. Initial plans for assembly and production of the final product should also be considered here. The output from this phase is a rough geometric design and a functional description of the different sub-systems. By evaluating different system ideas and combining different solutions for sub-systems weak spots can be eliminated and the best layout can be obtained (Gebhardt, 2003).

Step 4: Detail design

The phase of detail design will include finalising all necessary specifications for the system. This will include setting tolerances, materials and geometries of all parts of the system. The output from this phase will be the control documentation, for example drawings and specification of purchased parts. Gebhardt (2003) states that in this phase it will be important to pay attention to all details associated with the new system since difficulties frequently arise when there is a lack of attention to details.

Step 5: Testing and refinement

The testing and refinement phase involves the construction and evaluation of preproduction versions of the product. Examples of the goals of this phase are to verify different functions and that the system can be produced by the intended methods. The preproduction versions or prototypes should identify the necessary changes to be made to the final product.

Step 6: Production ramp-up

During this phase the product is made using the intended production system. The purpose is to solve any remaining problems connected to the production process and to make the workforce familiar with the new parts to be produced. The transition to the on-going production from the production ramp-up is usually conducted gradually until the necessary problems are solved.

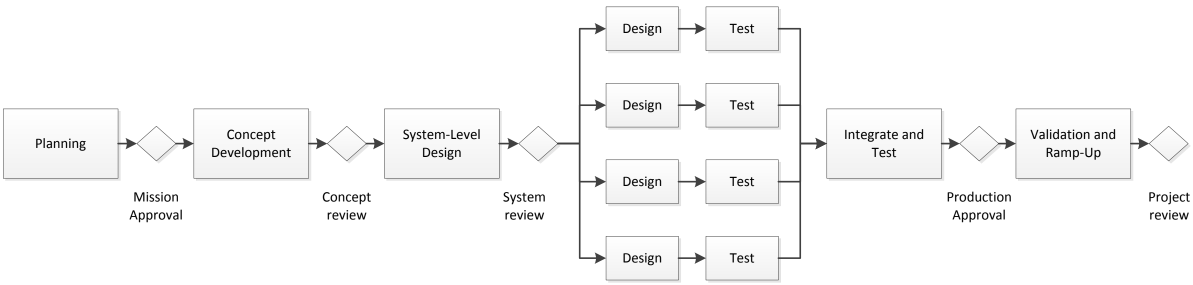

FIGURE 6 OUTLINE OF A PRODUCT DEVELOPMENT PROCESS FOR COMPLEX PRODUCTS

STAGE-GATE PROCESS

The product development process outlined by Eppinger & Ulrich (2012) in figure 6 can be referred to as a stage-gate process. Examples of stages can be concept development and planning and the gates are located between two stages, for example concept review and system review. By using a stage-gate system it will be easier to recognise the product innovation as a process (Cooper, 1990). Stage-gate systems can apply process-management methodologies to the innovation process. For each gate there is a set of pre-determined deliverables and certain specified quality criteria that the product must pass in order to proceed to the next stage. The work is done within each stage and the gates ensure that the quality is sufficient. The gate-keeping group, who decides go/no-go, is typically a multidisciplinary and multifunctional group and have enough authority to approve the needed resources for the next stage.

There are many studies conducted on the product development process that consider the early phases as most crucial in a product development project (Verganti, 1999). This is because time and cost required for any corrective action will increase as the development process proceeds and enters later stages. Hence, decisions made in the early phase have the highest impact on the outcome since they are most likely not to be changed. The problem that occurs is obvious: the most important decisions are to be taken when uncertainty is very high. The strategy taught in most project management literature is to reduce the uncertainty as much and as early in the process as possible (Engwall, 2002). How uncertainty, cost and time of corrective actions vary throughout the product development process is stated by Verganti (1999) and visualised in figure 7.

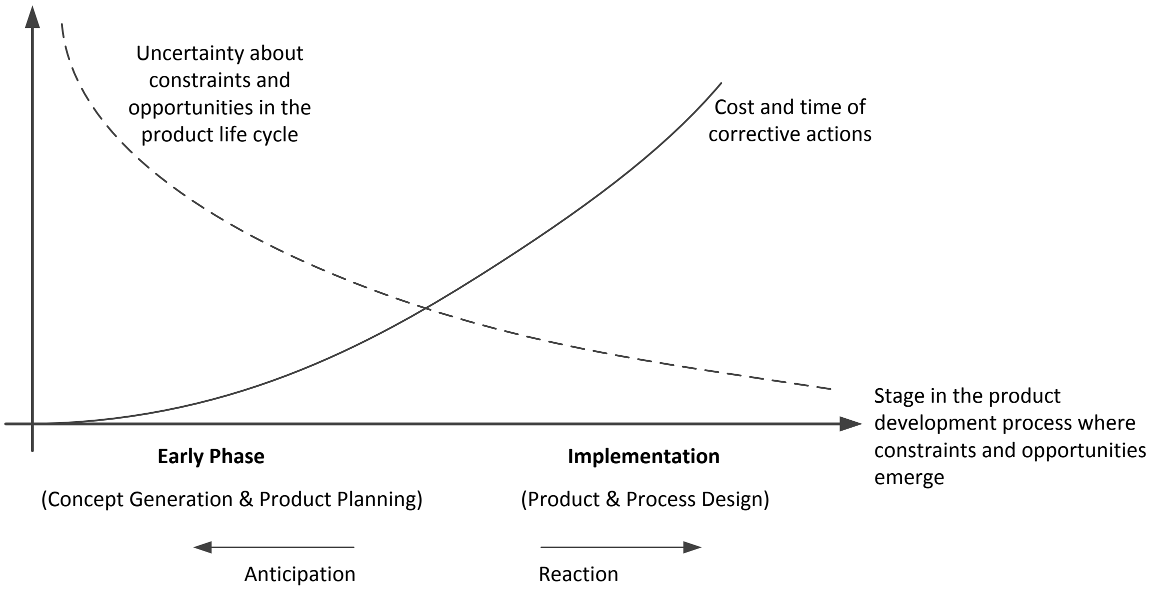

FIGURE 7 UNCERTAINTY AND COST AND TIME OF CORRECTIVE ACTIONS IN THE PRODUCT DEVELOPMENT PROCESS

RAPID PRODUCT DEVELOPMENT (RPD)

As mentioned in the previous section regarding product development, several authors states that the time-to-market of the product is crucial, which means that the time for developing the products become continuously shorter. The success of these developing processes will depend on short and iterative development cycles (Bullinger, Warschat, & Fisher, 2000). There exist a couple of new methods providing this gathered under the term of "rapid product development". The success of managing a rapid product development will depend on making good trade-offs between four possible objectives within the development cycle: (i) development speed, (ii) product cost, (iii) product performance and (iv) development program expense (Bernard & Fischer, 2002). The reduced product development time cannot be at the expense of performance, cost, quality and product reliability and this will contribute to the need of a change in the traditional way of developing products.

Significant for the Rapid product Development process is the frequent production of prototypes (Bullinger, Warschat, & Fisher, 2000). Beside the ability to quickly develop and produce products and services, the ability for producing prototypes rapidly has increased correspondingly (Trygg, 1994). Today there exist a number of different methods for rapid production of prototypes. Examples of these are generative prototyping technologies like e.g. Stereolithography (STL) (Bullinger, Warschat, & Fisher, 2000). These advances in the area of rapid prototyping have reduced the cycle time from weeks down to hours and days (Trygg, 1994). By having a shorter lead time of prototype production it will lead to a more efficient development process. Other advantages of using rapid prototypes are stated by McGrath (1996), some examples of these are listed below:

- Debugging early designs
- Eliminating more expensive early prototypes
- Testing customer reaction to new industrial design

Besides short iteration cycles, cross-functional teams are an essential feature of the RPD concept. The increasing complexity of the products will require early collaboration and coordination (Bullinger, Warschat, & Fisher 2000), in addition to the increasing need for communication. The increasing need for communication in projects with high complexity is something also stated by Mintzberg, (1983). With increasing complexity the parts of the system will increase and the number of interrelations between them will also increase.

ORGANISING PRODUCT DEVELOPMENT

In order for firms to have a successful product development they must organise their staff to have an effective implementation of the process (Eppinger & Ulrich, 2012). Two classic organisational structures are the functional and project organisation.

Within the functional structure the organisational links are primarily within the same functions. When members of a functional structure are part of a project there will be no strong connection within the project, the strong link will still be towards their own function. The functional organisation tends to breed both specialisation and expertise within the function.

In contrast to a functional organisation the project organisation will consist of strong links within the project. Each group will consist of people from different functions focused on the development of a specific product or product line. The performance of the group members will be evaluated by the project manager as opposed to the functional structure where the functional manager evaluates each worker. The fundamental strength of a project organisation will be high focus and ability to handle cross-functional integration particularly well (Wheelwright & Clark, 1992).

To enjoy benefits from both the functional organisation and the projects organisation, a matrix organisation can be an alternative (Maylor, 2010). Situations where this type of structure is appropriate can be:

- When there is a need to process large amounts of information simultaneously.
- When there is a need to share resources, one project cannot fully use the dedicated resource.
- Where the activities of the operations have more than one orientation, for example multiple customers or geographical differences.

The matrix organisation has two orientations, the heavyweight team structure and lightweight team structure (Wheelwright & Clark 1992) and are visualised in figure 8. The lightweight structure resembles the functional structure, those assigned to the team stays physically in their functions and with strong links to the function. Each function appoints a liaison person to represent the function on project meetings, which is referred to having a “lightweight project manager”. The position is more of a coordinating role than of a project manager position.

When using a heavyweight team structure the manager has direct access and responsibility of the people working in the project. The heavyweight project manager is often a senior person within the organisation that holds great expertise and experience. Teams using this type of structure often benefit from improved communication, stronger commitment to the project and more focus on cross-functional problem solving.

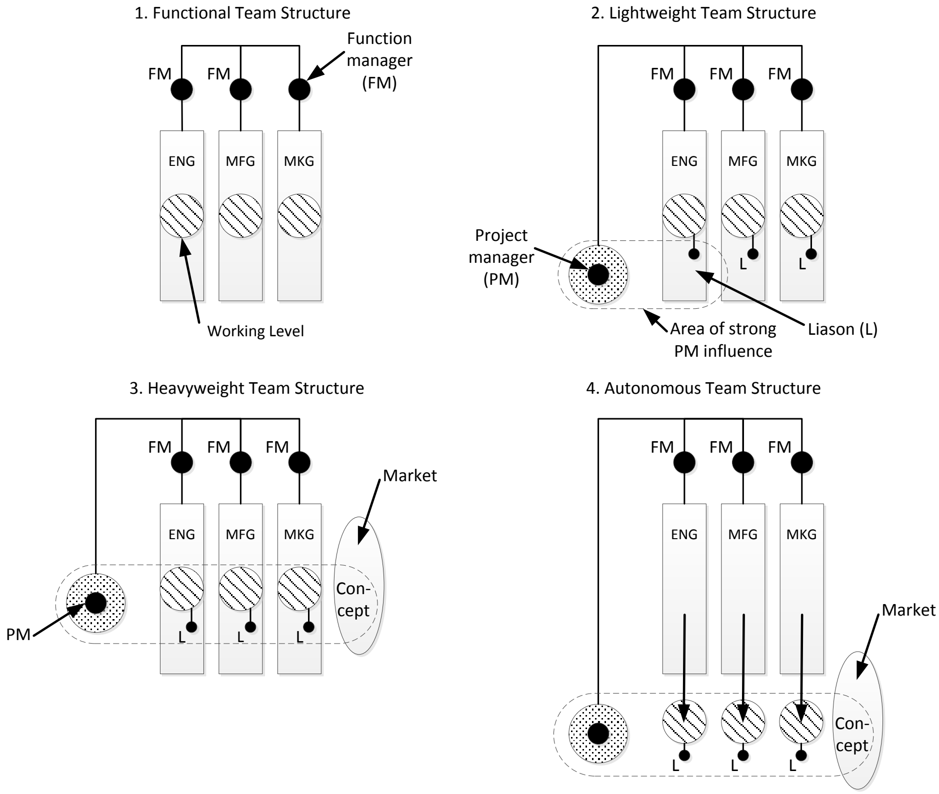

FIGURE 8 DIFFERENT TYPES OF TEAM STRUCTURES IN PRODUCT DEVELOPMENT PROJECTS

Depending on which performance factors that are critical for success the choice of organisational structure will vary (Eppinger & Ulrich, 2012). To answer the question of which organisational structure that will be most beneficial to use a number of questions can be asked:

- *How important is cross-functional integration?*
  Functional organisations can have difficulties to be fully cross-functionally integrated. Project organisations will have easier to integrate and coordinate across functions.

- *How critical is cutting edge functional expertise to business success?*
  When expertise and specialisation must be built up and retained over several product generations functional links will be necessary. Project organisations can have trouble in acquire the necessary competence needed to develop products where specialisation and expertise is needed.

- *Can individuals from each function be fully utilised for most of the duration of a project?*
  Depending on the amount of resources a project requires from a specific function different organisational structures may be beneficial. The structure of a project may need to be oriented more towards the functional organisation if the project is not able to fully utilize a resource.

- *How important is product development speed?*
  A project organisation tends to resolve for example conflicts and problems quickly and allow for the project to continue with a shorter interruption. The functional organisation will have a more complicated process of solving problems when more functions and people need to be involved.

McGrath (1996) describes that successful product development teams need to be organised in order to achieve effective *communication*, *coordination* and *decision* making. The lack of communication has been the cause of many product deficiencies and project delays. The high degree of uncertainty within a development project will require good communication, both vertical and horizontal. When developing new products it will require the completion of an extensive number of activities. Not coordinating these properly can cause project delays and ineffective use of resources. A product development process will include making thousands of decisions. Effective project teams make better and quicker decisions which allows for the project to progress.

Malmgren & Ragnarsson (2001) has identified that communication and coordination will be of high importance when projects are complex and advanced products are to be developed.

CLASSIFICATION OF DIFFERENT DEVELOPMENT PROJECTS

The design of the product development process is depending on what kind of products that are produced and how the product portfolio is designed. Products can be classified in different categories depending on their characteristics. Wheelwright & Clark (1992) explains that establishing an appropriate classification result in a simpler explanation of management's strategy regarding planning, staffing and guidance of individual projects. It also helps to develop aggregate projects plan since different projects requires different levels of resources and commitment. Below are suggestions from two different authors on how to make an appropriate division.

The generic development process used in a market-pull situation where customer needs can be identified as a market opportunity usually uses available technique within the firm to satisfy the needs. However it exist other products where other types of development projects can be identified and a suggested division from Eppinger & Ulrich (2012) is presented below:

TECHNOLOGY-PUSH PRODUCTS: Development of new technique, made available for the market and which demonstrates the benefits of the product which create a need from the customer. The products are often built upon traditionally materials or processes.

PLATFORM PRODUCTS: Platform products are built upon pre-existing technology, which is a beforehand proven technology platform from evaluation of meeting customer needs. Apple IPhone operating system is one example of such platforms. The initial investments of these platforms are very high which therefore need to be spread over several products in order to spread the cost. Similar to technology push products in that sense that the product concept embody a particular technology.

PROCESS-INTENSIVE PRODUCTS: Here, the production process puts constraints on the product which is usually produced in high-volume series. Either the production process is developed simultaneously with the product or the production process can be decided in advance and the product is then developed but constrained by the production process.

CUSTOMISED PRODUCTS: Different configurations are made from a standard product in order to meet specific customer needs. There is often a highly detailed development process when developing customised products including a well-defined sequence to follow in order to ensure a structured flow of information.

HIGH-RISK PRODUCTS: Products that are significantly affected if there is high uncertainty in technical and market changes. Other risks can be budgeting and schedule risks. The product development process is often modified in these types of products to include a risk analysis in order to classify different type of risks.

QUICK-BUILD PRODUCTS: Often connected to software and electronics that enable a rapid building and testing cycle which allows an early customer feedback. Using rapid iterations with the customer when developing products will benefit from having a flexible and responsive product development process. This could be of importance in order to make priority of different changes when having much feedback from rapid iterations, in order to conduct the most important changes first.

COMPLEX-SYSTEMS: Large-scale products that include many sub-systems and components which include extensive testing and validation. There is often a need of modification of the generic product development process which address a number of system-level issues.

Wheelwright & Clark (1992) suggests another division which is described below:

R&D AND ADVANCED DEVELOPMENT PROJECTS: Projects that creates knowledge know-how and know–why and is a precursor to commercial development. Important to consider resources made available for these kind of project in the aggregate project plan. These projects can be seen as precursors to the commercial development.

ALLIANCE OR PARTNERED PROJECTS: All type of projects could be designed as alliance or partnered projects. The main reason for these kinds of projects is that both parties can have the possibility to take advantage of each other's resources. Often used to filling in gaps within the development when the resources are lacking or when strategic opportunities is identified by smaller companies that does not have enough resources to benefit from the opportunity.

INCREMENTAL OR DERIVATIVE PROJECTS: Includes improvements on existing products or processes and can be seen as upgrades. These projects can be used for both cost reducing existing products and add-ons or enhancements to existing production processes. Require few resources due to that they take advantage of existing products by extending their applicability.

BREAKTHROUGH OR RADICAL PROJECTS: Involves significant change in products and processes and can possibly create new product categories which include new functionality and technique. Most effort is put on the product and not on the manufacturing process. These projects have extensive focus on satisfying new customers.

PLATFORM OR NEXT-GENERATION PROJECTS: Provides a base for a product that could evolve over time and requires significantly more resources than incremental developments. These projects cannot be seen as a development of a single product and its manufacturing process. To act as a platform, three essential characteristics need to be satisfied, these are presented below.

- Core performance capabilities that match primary needs
- Support of an entire product/process generation
- A link to previous and subsequent generations

CHANGE BEHAVIOUR

In both large and small engineering and manufacturing organisations there is a great resistance towards changing how work are to be conducted e.g. the product development process (Bean & Radford, 2000). There exist a number of reasons why an organisation is resistant to change, McGrath (1996) states a number of reasons and some examples of these are listed below:

- *Product development has not been viewed, managed or taught as a process:* Traditionally product development has been thought of as an art, not something that could be described as a process. It was not possible to be managed, it just happened.

- *Improvements usually require a cultural change:* Cultural change is always difficult to implement. Changing people's way of working always involves great uncertainty for the individual worker who usually reacts with reservation (Rubenowitz, 2004).

- *The changes are too extensive:* The product development process cuts through many functions and departments of the company. When this process is to be changed it requires a substantial amount of both time and resources for this to be thoroughly conducted.

To achieve a cultural change usually involves changing the behaviour of people. Bean & Radford (2000) states a number of different strategies to achieve a change in behaviour of people:

- *Self-discovery*: The most effective way of achieving a change is not to have to work for it. By making the individual realise that a change is needed and making he/she conduct the change is the most beneficial method. Coaching is a very vital part in making this work.

- *Issue or problem ownership*: By assigning an individual or a group a specific problem or issue to solve will force ownership of the problem. This process also needs to be well supported and provided with resources and time to conduct the work needed to come through with the change.

- *Changing the reward system*: Many people tend to act in ways that will bring them the greatest award. By changing the reward system in order for it to support the desired change can aid the process in the right direction. A successful reward system should encourage the appropriate behaviour and penalize the deviant or inappropriate behaviour.

- *Appraisal and reinforcement*: When feedback is to be provided it is important to encourage the proper behaviour and at the same time identify inappropriate behaviour as quick as possible and corrected.

- *Executive management involvement*. Top management needs to be involved and clearly state his/her opinion regarding the issue that is going to be changed.

PROTOTYPES WITHIN PRODUCT DEVELOPMENT

A prototype can have many interpretations in the context of product development, for a developer of a satellite it might be the final product or for a developer of a ballpoint pen which might use 10 different prototypes during the product development (Wall, Ulrich, & Flowers, 1991).

There exist a number of different definitions for prototypes used within product development. Eppinger & Ulrich (2012) defines a prototype as "an approximation of the product along one or more dimensions of interest". With this definition any entity exploring at least one aspect of the future product can be called a prototype. The process of developing such an approximation can be called *prototyping*.

Prototypes can usually be defined along two dimensions (Eppinger & Ulrich, 2012). The first dimension is to which degree the prototype is physical as opposed to analytical. An analytical prototype represents the product in an intangible way, usually done by for example computer simulation or computer models using three-dimensional visualisation these prototypes is called virtual prototypes. The physical prototype is a tangible representation of the product. Example of physical prototypes can be models that look and feel like the product or hardware used to verify certain functionality of the product.

The second dimension by which the prototype can be classified is to which extent the prototype is focused as opposed to comprehensive. A focused prototype implements only one or a few attributes of the product, an example of this type of prototype can be a foam model visualising only outer geometry or a simple construction to test a specific function within the system. A comprehensive prototype is closely related to the more finalised product since it is a full-scale and fully operational version of the system which implements most of the attributes of the final product. Comprehensive prototypes are often used in cooperation with the customer in order to identify remaining flaws before the production ramp-up can start. Liou (2008) gives an example of how different prototypes can be divided according to two different dimensions which is described and visualised in figure 9 below.

- Form model – Physical model which is focused on eg. the visual appearance
- Paper prototype – For eg. a sketch of the concept
- Alpha prototype – System construction on sub-system level
- Beta prototype – Full-scale functional prototype
- Production prototype – Comprehensive prototype used for production ramp-up
- Virtual prototype – Computer model or simulation to analyse product

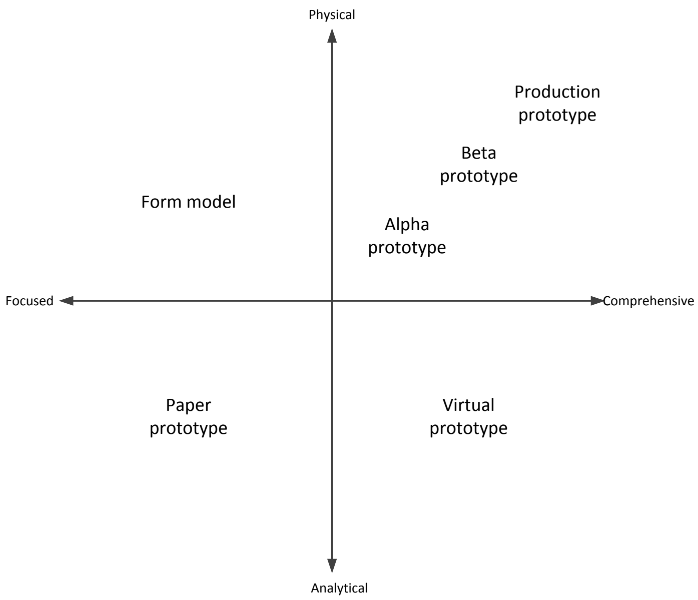

FIGURE 9 TYPES OF PROTOTYPES IN RELATION TO DIFFERENT DIMENSIONS

Beaudouin-Lafon & Mackay (2007) states two types of prototyping strategies to be used which can be connected to the above dimensions mentioned by (Eppinger & Ulrich, 2012). The prototypes can either be horizontal or vertical. A horizontal prototype visualises the entire system at some level however with no underlying functionality. This is to be compared with the vertical prototypes which are more focused on one design question. They can be created early in the project before the entire architecture of the product is decided.

Johansson, Råberg & Killander (1996) identifies three types of models/simpler prototypes that can aid the product development process. The identified models are:

- *Visualisation model:* Is used to visually resemble the product. Different demands on this model can be size, feeling and accuracy in shape.

- *Control model:* This type of models can be used for testing for example assembly and fixtures to be used during production. Other areas of usage can be for testing if certain space for a componenet or sub-system is sufficient.

- *Process models:* Is used for simplify the production process for the later prototypes or products. Can be used for testing tools in the production plant or different types of moulds to be used.

Gebhardt (2003) states that the demands on the models differ according to the degree of progress the product development has reached. The definitions are often characterised by the planned use and by the specific definitions for certain branches and this contributes to a large number of various terms and definitions of prototypes. Gebhardt (2003) suggests a classification for various kinds of prototypes as follows:

- *Proportional model*
  Should support fast exchange of communication regarding the intended product properties and enables a fast consensus on the product idea. It should show the outer shape and the most important functions.

- *Ergonomic model*
  Is intended to support rapid decision about feasibility. Can show important functions of certain importance.

- *Styling model*
  Has the outer appearance very close to the real product and should have high surface finish. Can enable for e.g. customers to give feedback at an early stage.

- *Functional model*
  Shows some or all important functions but not necessary with the correct outer shape. Examples of properties to be tested can be assembly, maintenance and kinematics.

- *Prototypes*
  Resembles the product close or very close. The only difference against the serial sample can be for example the production process. Enables testing of one or several product properties and can enable preparation for market introduction.

Eppinger & Ulrich (2012) lists different types of industries in relation to each other with respect to the technical and market risk and the cost of comprehensive prototypes. These are visualised in figure 10 below.

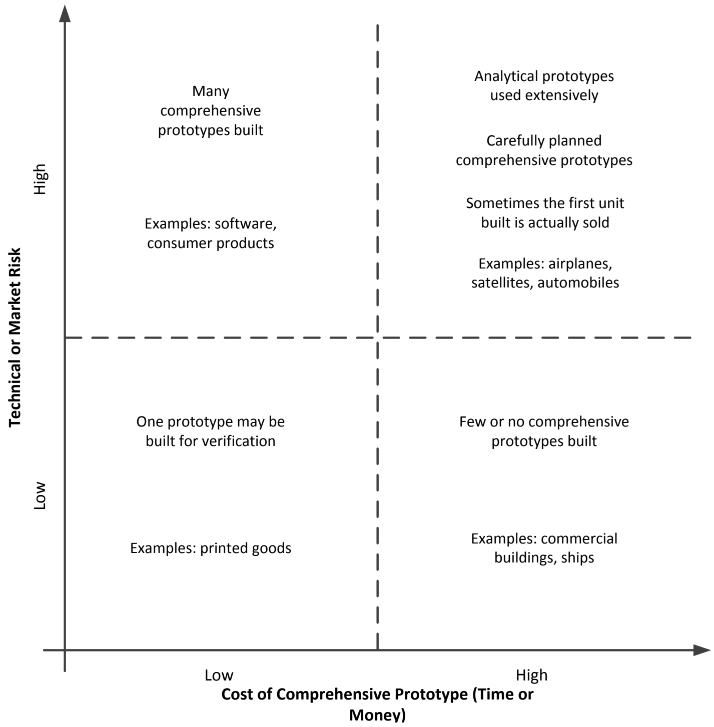

FIGURE 10 DIFFERENT PROTOTYPES IN RELATION TO TECHNICAL OR MARKET RISK AND TIME OR MONEY

PURPOSE OF USING PROTOTYPES

Before a prototype is made, it is very important to define the purpose of the prototype in order to maximise the value with a minimised use of resources (Liou, 2008). Eppinger & Ulrich (2012) lists four different purposes of prototypes when used within a product development process and they are listed below:

- *Learning*: Prototypes are often used to answer questions like: "Will it work" or "How well does it meet the customer needs". By getting these questions answered the product development team will accumulate knowledge for how to proceed with the development work.

- *Communication*: Prototypes are a powerful tool to enrich communication with stakeholders both inside and outside the organisation. By using prototypes it will be easier to communicate with e.g. top management, investors, customers and extended team members and it will increase the quality of the communication (Gebhardt, 2003). The physical prototypes are most beneficial to use for this purpose since they are powerful tools to eliciting feedback from customers (Liou, 2008).

- *Integration*: Prototypes can be used to ensure that sub-systems and components of the product work together as intended. Comprehensive physical prototypes are the most effective in achieving the integration purpose, this because it forces the different parts of the development team to coordinate and assemble the different sub-systems making sure that the physical interfaces them between works.

- *Milestones*: Prototypes can be used in combination with the project framework. By integrating prototypes as milestones, project progress can be shown in a very tangible way. Milestone prototypes can demonstrate that certain functionality has been reached or other specified demands can be fulfilled.

In addition Liou (2008) states that prototypes can be used to resolve uncertainty in the early stages of the development process, validate evolving user requirements and pre-train users or to create a marketing demonstration.

By using prototypes early in the process, the risk of innovation can be reduced (Barkan & Iansiti, 1993). Early tests with even a rough prototype can help identifying potential problem areas and reduce the risk. The early prototyping strategy allows for more adaption early in the process when the flexibility is still high and the cost is low.

CONNECTING PROTOTYPES TO THE PRODUCT DEVELOPMENT PROCESS

Prototypes play an important role in testing the design and consequently also the progress of the entire development, therefore it will be of great importance how the company connects prototyping to their development process (Wheelwright & Clark, 1992). Below it will be accounted for different authors view on how this can be done. Since the development process often is divided differently depending which author is the writer, the development process below is divided in to three general stages which is applicable for all cases.

CONCEPT DEVELOPMENT

Initial concept development will constitute of making breadboard models of the different concepts (Wheelwright & Clark, 1992). Barkan & Iansiti (1993) states that in the generic R&D phase (which usually precedes the concept phase) rapid learning can come through a series of rapidly produced prototypes of sub-systems and components. Focus can be on time and cost and less on high fidelity compared to the production process. According to Gebhardt (2003) prototypes used during this phase should support fast decision about feasibility e.g. if the product should and is possible to develop. The first prototype should be developed in the end of this phase in order to verify critical functions (Johansson, Råberg, & Killander, 1996). Liou (2008) states that prototypes which are used early in the development effort can benefit from being simple when it comes to eliciting feedback from different stakeholders. When the prototypes is of simpler type, feedback is more likely to be gained regarding concept instead of details such as finishing or choice of material.

DETAILED DESIGN

During this phase the prototype unit should be able to demonstrate the functionality needed to meet the performance requirements for the product (Wheelwright & Clark, 1992). Gebhardt (2003) states that prototypes showing some or all the important functions should be used. In parallel to this "styling models" can be used which has the outer appearance very similar to the real product. According to Barkan & Iansiti (1993) prototypes should be used to resolve relatively detailed questions concerning e.g. configuration and compatibility which can be compared to what the above mentioned authors has stated within this stage of development.

PREPARATION FOR PRODUCTION

When the product development process has reached this later stage the prototype should resemble the real product and the remaining level of uncertainty must be low (Barkan & Iansiti, 1993). The prototype is not only to verify outwards against the customer but also pass tests related to testability and manufacturability (Wheelwright & Clark, 1992). Bean & Radford (2000) claims that production prototypes will always be a good predictor of the ultimate product quality, independent which dimensions of quality used.

IMPROVING THE USE OF PROTOTYPES

In the traditional form, prototyping is technically driven by different functions in different phases of the development process. The focus is primarily on evaluation and verification of the system, subsystem or components (Wheelwright & Clark, 1992). These authors lists four "best practices" that is applicable to any company and prototyping process that can improve how work is conducted within the development of prototypes:

LOW-COST PROTOTYPES

The progress from simpler models early in the development process to more advanced and complex ones in the end of the process appears natural. Traditionally the representativeness increases at the same time as the prototypes become more advanced. However Wheelwright & Clark (1992) suggests an improvement of the early models and that effort should be invested in increasing their representativeness. By doing this, contribution is made to strengthen the contribution of prototypes to the product development process.

PROTOTYPING PROCESS QUALITY

During the prototyping process it is common with many simple but costly mistakes, such as material problem or misreading a drawing. By avoiding these mistakes and increasing the quality of the process, this can contribute to improve the reliability and learning that occur. At the same time improving the response time in prototyping- also known as rapid prototyping- will contribute in improving the quality of the prototype process. It will be especially beneficial to have short response time when the prototype is to represent current thinking in the early phases. Barkan & Iansiti (1993) states that rapid construction of many prototypes early in the process contributes to quickly identify and solve problems.

TIMING AND SEQUENCE

Many firms have the experience that individual prototype cycles should not be overlapped. When overlapping, it will for example be easier for people to lose track of the status of the project and which problems that are solved and not. This will be most crucial during the detailed design (Barkan & Iansiti, 1993).

BUILDING KNOWLEDGE

By systematically study the different problems that occur in each prototyping cycle, this can contribute to plan these cycles better in the future. By capturing and enhancing knowledge of a prototyping process the speed, quality and efficiency of prototyping process can increase. Bean & Radford (2000) states that the prototype development process will always be subject to better organisation and coordination and that learning about the process itself is important.

Barkan & Iansiti (1993) has identified certain patterns how to use prototypes in the most effective way when developing products, some of them are listed below:

1. Innovation should be focused in the areas where there are well-recognised sources of risks and uncertainty.
2. When products are to be developed that contains new and unknown technology, the risk can be minimised by using early, frequent and rapid prototyping.
3. Errors are searched for and found as early as possible in the process.
4. Prototypes are used early to identify unexpected system-level problems coming from the interaction between different sub-systems. They are in addition used to integrate the activities from different parts of the cross-functional teams.
5. The full system prototype should be used to confirm the design and not find still undetected problems.

PLAN FOR PROTOTYPING

To ensure that the prototyping effort contribute to the overall goal of the product development process it will be beneficial to define a plan for how the prototype process is to be conducted. An outline for a plan is presented below based upon four steps suggested by (Eppinger & Ulrich, 2012):

STEP1: DEFINE THE PURPOSE OF THE PROTOTYPE

It will be important to define the purpose of why the prototype is to be made. The different purposes of why a prototype can be made are stated earlier in this section.

STEP 2: ESTABLISH THE LEVEL OF APPROXIMATION OF THE PROTOTYPE

It will be important to decide to which degree the prototype will be approximated compared to the actual product. Questions to be answered can be for example if a physical prototype is necessary and which material is should be constructed by. The best prototype is the simplest prototype that will fulfill its purpose (Liou, 2008).

STEP 3: OUTLINE AN EXPERIMENTAL PLAN

The use of a prototype can be seen as an experiment when implemented in a product development process. It will be beneficial to have a plan to follow, e.g. regarding how the test is to be conducted, what to be measured and how to analyse the data from the test.

STEP 4: CREATE A SCHEDULE FOR PROCUREMENT, CONSTRUCTION AND TESTING

Since the building and testing of the prototype can be seen as a sub-project within the overall development process, it will be beneficial create a schedule for the testing, construction and testing of the prototype.

In addition Liou (2008) suggests a fifth step to the above mentioned plan which is to perform a more detailed planning regarding the time and cost associated to the prototype.

If it is decided upon a physical prototype, especially if the system is complex, planning and management will require more attention. Liou (2008) suggests the following tasks listed below to be conducted in order to handle the complexity:

TASK 1: PROTOTYPE CONCEPTUAL DESIGN

When a more extensive prototype is to be made it will be important to consider the entire concept of how to design and produce the prototype.

TASK 2: CONFIGURATION DESIGN OF PROTOTYPE PARTS AND COMPONENTS

The conceptual design will result in concept utilizing both standard components and other non-standard parts. It is however strongly recommended to use standard parts in order to save time and money during the prototyping process. By reusing existing parts, time and cost can further be minimised.

TASK 3: PARAMETRIC DESIGN

When needed, specific materials and tolerances for the prototype must be specified.

TASK 4: DETAILED DESIGN

This task should supply remaining tolerances, dimensions and material information for the engineering drawings.

PROTOTYPING STRATEGIES

Depending on which type of development project that is conducted there exist differences in how to use prototypes most optimal. Effective prototyping requires understanding which questions to ask, when to ask them and how to answer them (Wall, Ulrich, & Flowers, 1991). Wheelwright & Clark (1992) has stated three different strategies for how to work with prototypes depending on which type of projects they are to be used in. The prototyping programs differ in a number of dimensions and a summary is listed below in table 1.

Dimensions	Models		
	Traditional	**Revised traditional**	**Periodic**
Driving force	Technical performance	Technical/ Commercial performance	System performance
Focus	Evaluate design	Design intent and customer satisfaction	Superior system solution
Control of cycles	*Early:* Engineering *Middle:* Engineering *Late:* Manufacturing	*Early:* Engineering *Middle:* Engineering *Late:* Manufacturing	*Early:* Project team *Middle:* Project team *Late:* Project team
Responsible for building	*Early:* Subcontracted *Middle:* Engineering model shop *Late:* Plant	*Early:* Engineering model shop *Middle:* Model shop in manufacturing *Late:* Plant	*Early:* Engineering model shop *Middle:* Production line *Late:* Commercial production line
Involvement of customer	Limited to testing in late phases	*Early:* Eavaluation of mock-ups *Late:* System evaluation	*Early:* Customer test of prototypes *Late:* Extensive customer field test
Test criteria	*Early:* Functionality by component *Late:* System functionality	*Early:* Functional/ fidelity *Late:* System functionality/ fidelity	*Product:* System functionality *Process:* System functionality
Link to management milestones	*Limited:* Milestones reviews based on calendar	Milstones tied to prototype phases	Prototype cycles are the management milestones

TABLE 1 SUMMARY OF PROTOTYPING PROGRAMS

The traditional model is technical, focused on design intent and controlled by design engineers until late phases where manufacturing becomes involved. The revised model adds a greater focus on both customers and commercial performance but preserves the core from the traditional model. The last model is called periodic prototyping. The focus with this model is to achieve a superior system performance which is achieved by extensive cross-functional work throughout the product development process and the prototypes are used as communication tools.

The different dimensions are shortly elaborated and explained in the list below:

- *Driving force:* What is driving the development of the prototype? Should the system have superior performance or should different technical functions be superior.

- *Focus:* Will explain the scope of the prototyping program and what to focus on.

- *Control of cycles:* Will explain who in the organisation that will responsible for the activities conducted within the specific prototyping process

- *Responsible for building:* Defines who will manufacture the prototype. By using a subcontractor the lead time might be shortened but important knowledge can be gained by manufacturing the parts in-house.

- *Involvement of customer:* Defines how much and when in the development process the customer becomes involved and will be able to provide feedback.

- *Test criteria:* Focus on the question of what is to be verified in each phase of the development process and what test to be conducted.

- *Link to management milestones:* Will describe how closely the prototyping process is connected to the project framework and in particular the management process and milestones.

Each of the above mentioned prototyping programs have different projects where they are more beneficial to use. Matching the wrong type of project with incorrect prototyping program can create unbalance in the project or that unnecessary resources are wasted. Wheelwright & Clark (1992) has matched the different types of projects (from earlier listed types of development projects), with an appropriate prototyping program in order to maximise the use of them.

Project type	Rapid response to engineering	Periodic prototyping	Early involvement of manufacturing
Break-through (technical)	- Creative, innovative results - Easily overcome problems with manufacturing	- Complexity and uncertainty slows down work - Technical compromise due to system focus	- Performance suffers, leading to many late engineering changes
Platform (new-architecture)	- Technical focus contribute to hurting the balance - Not sufficient system focus	- System focus achieves clear interfaces and integration - Team learning leads to early design convergence - Less late changes	- Performance inadequate, leading to late design revisions - Lack of balance due to manufacturing focus
Incremental (stable architecture)	- Lack early manufacturing involvement - Late revisions required for manufacturability	- Complicates project - System focus gives late changes due to technical problems	- Solves problem in design - Smooth ramp-up - Enhanced cost performance and reliability

TABLE 2 MATCHING PROTOTYPING WITH DIFFERENT TYPES OF DEVELOPMENT PROJECTS

COMMON MISTAKES USING PROTOTYPES

Even if using prototypes within the product development process results in a number of advantages, an improper use can lead to damaging the product development instead of aiding it. There exist a number of commonly seen mistakes of using prototypes within the development process (Liou, 2008):

- Too early commitment for a particular design
- The performance characteristics of the prototypes misguide the customer
- Using materials that do not reflect the final product which leads to that the performance data is misguiding
- Gaining a false view of how long time the product will take to produce based on the time required for prototyping.

Another potential pitfall using prototypes is referred as the hardware swamp (Clausing, 1994). The swamp is caused by a number of misguided prototyping efforts that do not contribute to the overall goals of the product development.

SUMMARY OF LITTERATURE

In this chapter, theory has been presented regarding product development process and an important tool in this process; prototypes. The product development process is a complicated process which can be associated with both complexity and uncertainty, depending on the market and the product to be developed. As a result of this, late changes often occur to extensive costs. An important aid to this process is the use of prototypes which can aid the product development projects in different ways.

Within the literature there is not one common definition of the different types of prototypes. Different authors have different definitions depending on the specific use. There is however a unified picture that in order to fully utilize the potential of prototypes they should be carefully planned, with for example specified purpose and the responsible for manufacturing the prototype. A specified purpose could be communication and integration. With a proper use, prototypes become a powerful tool that can for example both shorten the development time and reduce the cost of developing a product.

These different characteristics of prototype usage are to be compared with the usage at Saab and what specific benefits the product development process can take from using prototypes.

4. EMPIRICAL FINDINGS

Within this chapter a description will follow over the empirical data that has been collected. First, a description over the organisation at Saab and the product development process will be presented. Second, a description over how Saab today uses and interprets prototypes will follow. Finally data from the external companies that were interviewed will be presented.

ORGANISATION AT SAAB EDS

SAAB EDS in Gothenburg uses a traditional line organisation in combination with a project organisation, which is referred to as a matrix organisation (Maylor, 2010). Figure 11 below shows the structure of the line organisation and where the Mechanics & Environment division is situated. The Mechanics & Environment division is divided into different sections that are responsible for different areas within the product development process, such as mechanical design, verification, testing etc.

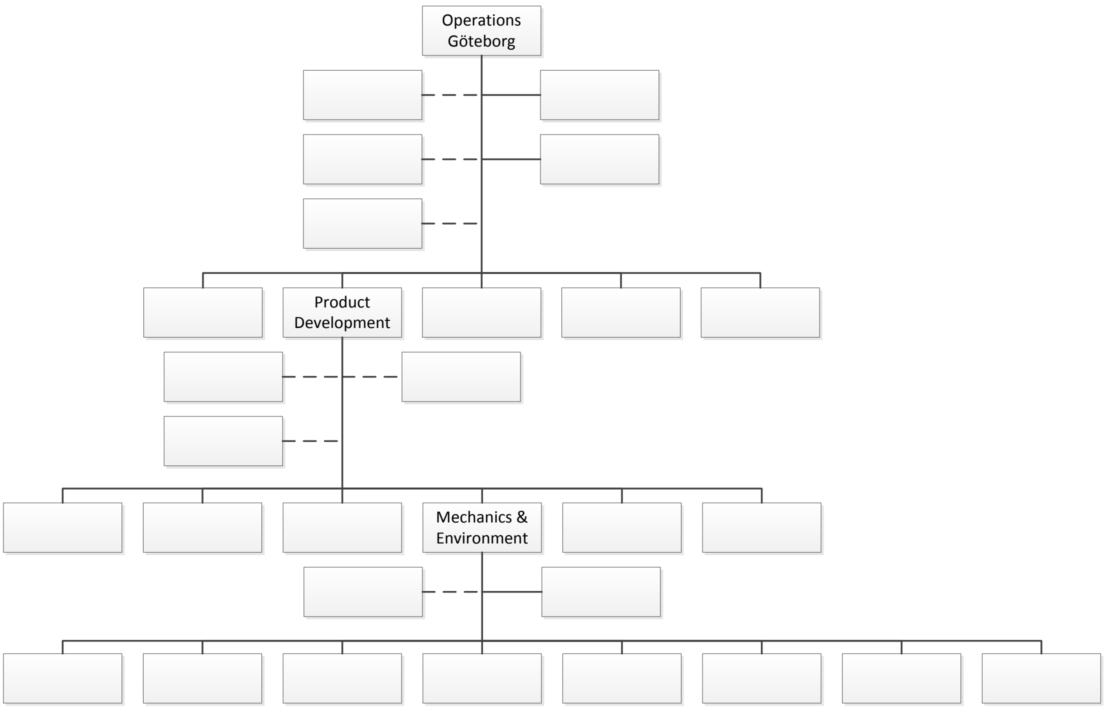

FIGURE 11 ORGANISATIONAL STRUCTURE AT SAAB EDS IN GOTHENBURG

Figure 12 visualises the matrix organisation and how engineers belong both to the line organisation and the project organisation. The different functions within the line organisation have authority within their area of expertise and decide how to develop the component or the system. The project organisation is responsible for the product, execution of the projects and is also responsible of controlling the time-plan and budget. Most of the projects cuts through each function within the company and the substantial part of personnel are "lent" to the projects from the different functional departments. Most of the projects at Saab EDS have a length of several years with many people involved and requires a high dedication from the project leaders.

As described above within each project at Saab EDS, there is an assigned project manager which has the overall control over the project. The project is then divided into sub-projects which are assigned a sub-project manager with the same responsibilities as the project leader but for a specific sub-system within the product.

There is a sponsor for each project that can be different key persons within the company or if the project is in collaboration with other companies, the sponsor can be several persons from both organisations. The sponsor can also be the customer if it is a customised project where the request comes directly from the customer. When conducting an in-house project without any specified customer, the sponsor is most often a person from the project management or the top management. The role of the sponsor is to have the authority over the budget and put it in relation to the overall economy within the organisation.

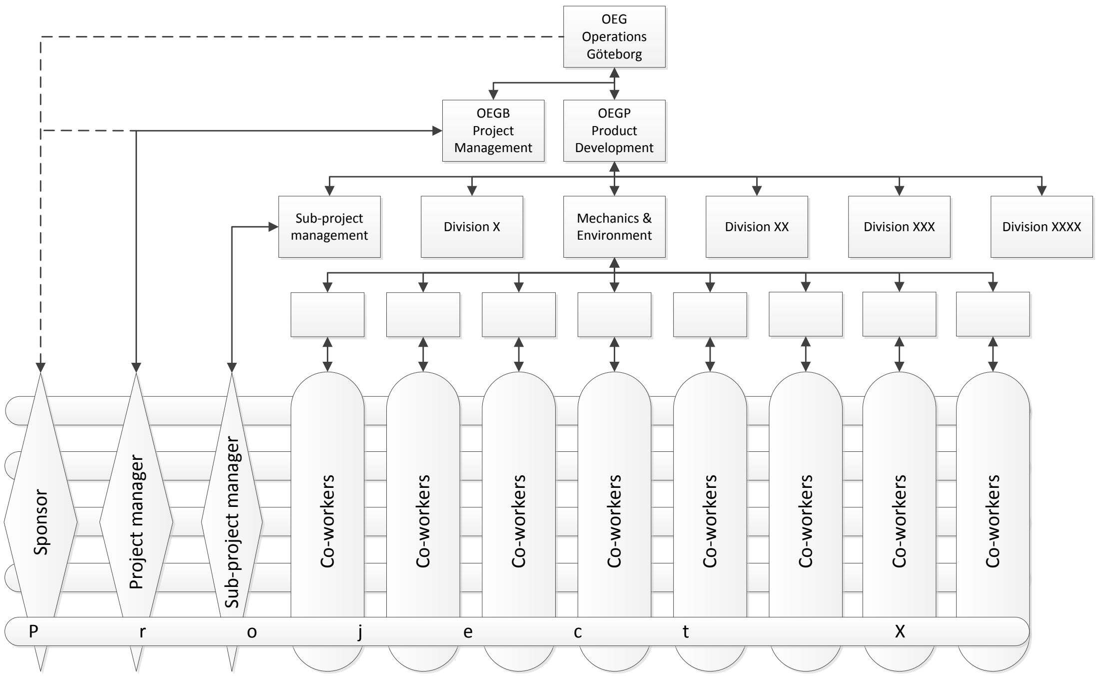

FIGURE 12 MATRIX ORGANISATION IN COMBINATION WITH PROJECTS

CLASSIFICATION OF PROJECTS

There are several projects in progress at the same time at Saab and the characteristics of the projects can be of high disparity. Below is a list of different types of projects conducted at Saab EDS in Gothenburg:

- RESEARCH & DEVELOPMENT OF NEW PRODUCTS

Approximately 20 percent of the total cost is allocated for research and development of new products. This is vital for the company to keep and expand market shares. This development have special characteristics, such as other kind of demands on deliveries and uses other processes but can be seen as projects that run over a long time. Often financed internally, but it exist exceptions where the customer is the financier.

- NEXT GENERATION PRODUCTS

These kinds of projects are conducted in average 10-15 years in between, where one of the product families is replaced with a new. These projects require a lot of resources and have an average development time of 3-5 years.

- UPGRADES AND ADD-ONS

Existing products is upgraded with certain functions and/or other value adding properties. The upgrades or add-ons often come from evaluations from customers that has needs arising after the product has been in use for a period of time. It can also be upgrades or add-ons that are proposed in-house where better solutions are invented.

- CUSTOM-MADE PRODUCTS

The most frequent type of project that derives from a standard product and modified to meet all customer needs and requirements. Allocations of resources are highly depending on the type of modifications, often extensive projects due to highly complex products and the need of many departments involvement.

THE PRODUCT DEVELOPMENT PROCESS AT SAAB EDS

In figure 13 the product development process at SAAB EDS is visualised. The top level shows the entire process from stakeholder requirements in the beginning and test and delivery in the end of the process. The figure also shows where in the process the Mechanics & Environment comes into the process and the three step sub-process are shown in the bottom of figure 13. Since the products that are developed at Saab EDS are of high complexity and should serve the customers for a long time, almost every project is built upon a certain product but modified to high extent in order to meet all the specific requirements from the customer. The products at Saab EDS have a long life-time and completely new product development for product families are seldom made, in average 10-15 years in between.

A flow chart over new product development is visualised in figure 13 below. There are different kinds of reviews conducted throughout the process with different focus and criteria regarding if the product can be approved into the next stage of the development process. To be able to proceed from one stage to another there are a number of criteria to fulfil in order to pass a certain gate. At this stage there is a decision taken which means that the subject is approved or needs to be revised/re-evaluated before going into the next stage of the development. These stage-gates are used to ensure that every development projects are accomplishing a certain degree of quality. Customers to Saab are often governments with high demands of product development process-standards (for e.g. ISO 9000) which require process models. This in order to be certified and this is one of the reasons for the stage-gate model used at Saab.

There is a Technical review (TRW) in each stage within the product development process and between the different stages there is a design review (DR) which is visualised in figure 13. In the Design test stage which is the last stage, there is also a hardware review (HRW) that needs to be approved before the product is approved for manufacturing. The TRW is a meeting that is connected to a checklist document that consists of several criteria regarding design aspects. The design engineer conducts the review in collaboration with managers and other responsible persons. Focus is on the content of documents and technical solutions on the product. The DR examines the product more comprehensive and includes reviews of supporting documents. The hardware review is the most comprehensive review and involves several persons and representatives from other departments and is a verification that should ensure a good design before releasing documents for manufacturing.

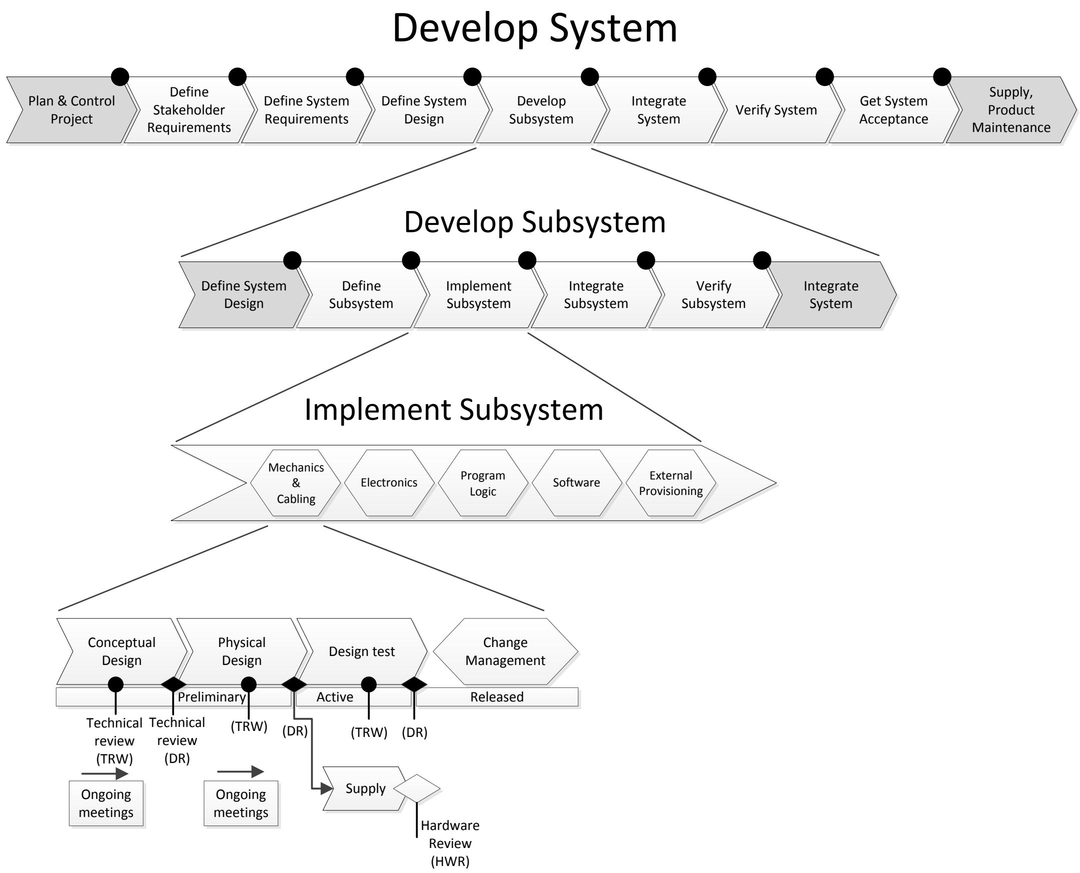

FIGURE 13 SHOWING THE PRODUCT DEVELOPMENT PROCESS AT THE DEPARTMENT OF MECHANICS & ENVIRONMENT IN SAAB EDS, GOTHENBURG

V-MODEL AT SAAB

Saabs model of how different designing and testing activities are coordinated on different levels is described by the V-model visualised in figure 14. When the product is complex and each system is divided into a number of sub-systems it will be beneficial to use this model for connecting design and testing. With the existing high demands on the products, it will be necessary to verify not only on system level but also verify different functionality before assembling it into the full system product. The V-model is a description of how this is made and how requirements are integrated in the design and verified in the later stages of product development.

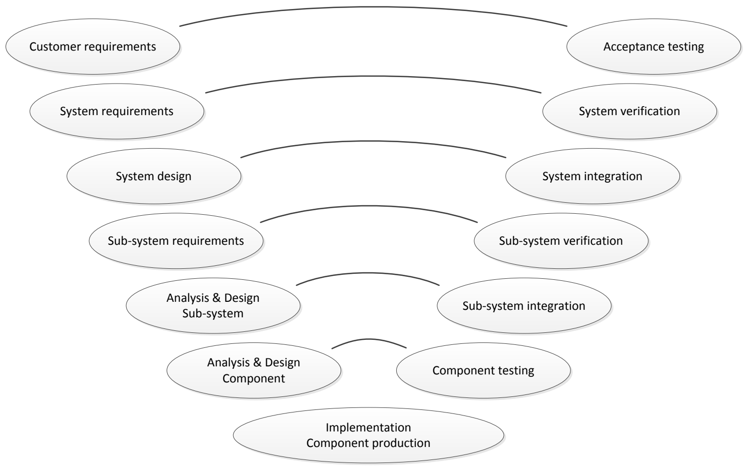

FIGURE 14 V-MODEL AT SAAB

FLOW OF DOCUMENTS

At Saab, there is an extensive flow of documents. All documents are handled through the PDM-system, which is called IFS. The PDM-system requires a specific way of working to establish a functioning system that enables correct revision numbers. The different revision numbers describe the status of the documents and how it is connected to prior related documents. Several documents are modified and used in several different projects which also make it highly important to have correct naming and revision numbers of the documents. Figure 15 below presents the flow of documents between departments (in this case the mechanical and manufacturing department) and the actual document status.

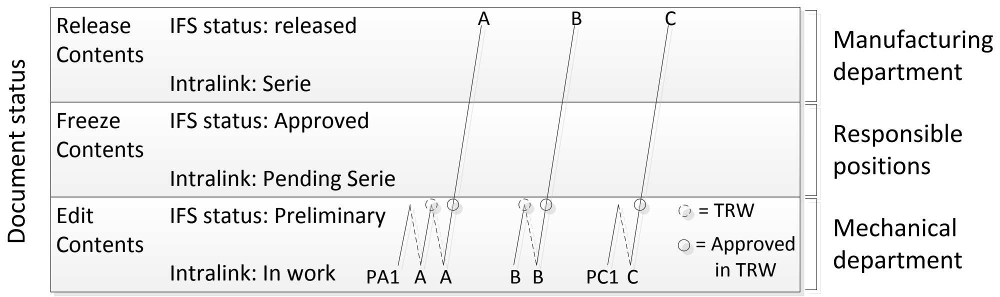

FIGURE 15 STATUS AND FLOW OF DOCUMENTS BETWEEN DEPARTMENTS AT SAAB

PRESENT PROTOTYPING AT SAAB EDS

Today there exist guidelines at Saab of how to produce and handle the development of prototypes. The purpose of these guidelines is to increase the usage of different kinds of prototypes in the R&D process, but also that the hardware is to be produced as quickly as possible for testing different functions or features. It was also desirable to have a common definition regarding the different types of prototypes in order for different people in the organisation to have a common picture of what is to be developed. In addition there exists a need from the design engineers for some guidelines to work after to create a unified working method.

Depending on which prototype that will be developed it requires different resources. There is a need of extensive use of different resources when manufacturing a prototype since it has only small deviations compared to the intended product. There is good support for manufacturing these prototypes but however there is a need of much coordination and many formal approvals along the process. Simpler prototypes such as mock-ups are not equally resource intense but since there is no complete process for manufacturing mock-ups it is highly different depending on each case. The specific amount of resources that is required for manufacturing a mock-up is up to the individual designer and there is no formal procedure to follow.

The usual procedure at Saab is that when the design department has finished the design for production the documents are released and put into R-mode. After this point the owner of the product is the manufacturing department. In order to make the process easier when producing a prototype the product was to be in P-mode even when to be manufactured, which is a deviation from the ordinary process. This was decided in order to make the design engineer (or design responsible) responsible for the prototype the entire time and make it easier for prototypes to be produced with less formal procedures. If the parts are to be produced by an external company, the design engineers needed to be in direct contact with the specific company to reduce the number of departments involved.

The prototypes were classified using three different denominations. These different classes can be seen below in table 3 together with the purpose and process exceptions for each type of prototype.

	Mock-up	Functional model	Prototype
Purpose	To quickly be able to construct visualisation models	To evaluate the concept/ functionality. Limited verification. Manufacturing can be done in parallel with the design of the system	Verification on design and producability. Limited verification or complete verification possible
Exceptions from ordinary process	A minimum of documentation for manufacturing needed. No demands on tolerances or measures on drawings	A minimum of documentation for manufacturing needed. No demands on tolerances or measures on drawings	No Product Revision information (PRI) necessary since controlled changeability is missing.

TABLE 3 CLASSIFICATION OF DIFFERENT PROTOTYPES

VIEW ON PROTOTYPES WITHIN THE ORGANISATION

Below is a summarised compiled text with the result from different formal and informal interviews conducted at Saab EDS in Gothenburg. The complete compilation of the interviews is presented in Appendix III, IV and V.

Questions that were asked were within several areas such as needs, usage and other relevant areas of prototype usage. The questions was focused on the usage of simpler prototypes, also called mock-ups, since this was the area of least prototype usage. Examples of which type of questions asked can be found in appendix II which contain an interview guide from one of the interviews.

-DEFINITION AND DIFFERENCES OF MOCK-UP/ FUNCTIONAL MODEL (FUM) AND PROTOTYPE

The majority of the interviewed people consider mock-ups to be used early and throughout the whole product development process and should be a tool that helps to verify concepts and designs. Mock-ups can be evolved over time to a higher degree of complexity. Mock-ups are showing correct dimensions, are manufactured in full-scale and is always a physical object.

Easier mechanical functions can also be integrated in the mock-up and interfaces against components can be tested as well. The mock-up should be quick to build and can be combined with dummies or old existing parts. One engineer within the organisation states that dummy is sometimes expressed as a mock-up in the organisation.

The Functional model (FUM) has a main purpose of testing certain more advanced functions, both electrical and mechanical compared to a mock-up. It is often worked in parallel with the mock-up and could be very similar to a prototype. The complete definitions of different prototypes are sorted according to different categories and are presented in Appendix V.

The group of interviewed people is considered to have a unified picture that prototypes are used within the organisation as a helpful development tool. Prototypes are used late in the product development process and used as a main purpose for verification and evaluation of the product. The prototype is seen as the first sharp product that is manufactured from complete documents and drawings. It uses the intended production method and this is stated by all people that was interviewed. The prototype should serve as a fully sharp product but can have small deviations compared to the real product as long as it fulfils the purpose.

-REASONS FOR NOT USING MOCK-UPS

Present at Saabs mechanical department there is not a frequent use of mock-ups. This type of aid is most often neglected and not seen as a helpful tool.

One of the main reasons for not using mock-ups can be connected to not having a sufficient and well-established process in the organisation. This makes it hard to encourage the use and to demonstrate that simpler prototypes are a powerful development tool in the product development process. Problems with the existing prototype development process is described by some engineers that it has a too weak link to the regular product development process and the guidelines are not sufficient enough. The majority also believes that there is a lack of supporting checklists and review documents.

There is a lack of knowing the value of using mock-ups in the organisation. Within the project framework there is often a lack of time and money that is allocated for prototypes. From several interviews it is stated that extensive mock-ups are not accounted for in the outline of the project and will require a lot of re-work to be assigned the necessary resources. As a result of this they are seldom built. Since all product development is conducted in projects and the project leader are responsible for the budget, the project leaders attitude to mock-ups is highly dependent on the experience of economic benefits made from mock-ups by the project leader.

From several interviews it emerges that people within the organisation have a strong cultural belief that 3D-visualisation is a sufficient tool in the product development process to accomplish a good product. Problems that arise from this are that people not working with 3D-visualisation can have a hard time visualising parts. In the organisation the cultural belief is considered to be connected to a short-term perspective, project perspective, and a belief that saving time and money can be achieved by excluding mock-ups in the development of products.

In the initial state of projects, it is often a rush to accomplish a certain delivery and mock-ups is believed not to create enough value compared to the investment. It emerges from several interviews that there is a lack of understanding that problem can occur early in the projects and that problems have a higher impact later in the development process compared to make the changes earlier. The lack of understanding is considered to be connected to ignorance from people and that problem often arises later in development when other departments are involved. This problem derives from what one engineer at Service & Maintenance describes as: "design engineers work too long before they are communicating with other departments".

– NEEDS FROM MOCK-UPS

Since several departments are involved from initial concept to delivered product used by the end customer there will be many different needs to fulfil from mock-ups. In addition for example serviceability will be an important feature to integrate into the products since this is a service also provided by the company. Market department can use mock-ups in combination with exhibitions to show an early physical model of the product. Design engineers will have the possibility to use simple mock-ups throughout the product development, from system-level to single component. Project and sub-project leaders can benefit from using system and sub-system mock-ups in combination with workshops for evaluation and as milestones within the project. From interviews with the system security and ILS department it emerges that they may in first hand use the mock-ups for early verification on security aspects and serviceability.

The use of mock-ups will minimise the risk connected to product development by identifying problems, remove uncertainties and to show progress, this in a simple and effective way. It also creates the possibility for early verification in the process and contributes to more effective reviews.

From 13 interviews it is stated that mock-ups should have the possibility to practically test and show simple functions, interfaces and create a feeling for dimensions. It should also act as a helpful tool for design engineers for ergonomics, serviceability, accessibility and packability studies.

Mock-ups should also act as a tool for communication by create understanding, provide a common picture and elicit the use of the product. It should also make it easier to have an early involvement with the customer and to be able to present concepts for potential customers.

-HOW TO USE THE MOCK-UP

Within the project framework, the mock-ups can be used as sub-goals and milestones. Due to products with high complexity, which result in more involved departments, the mock-ups should be used in workshops. Compared to 3D-visualisation, the mock-up should be used for physical verification and for implementation test on customer site.

The market department emphasizes the usage at exhibitions and sales meetings. The mechanical design department states that mock-ups can be used in collaboration with computer aided design (CAD) programs in order to get a "hands-on" feeling and to create correct measures on the component and between components.

From one interview made with a design engineer that is working with questions related to human factors it emerges that mock-ups is a vital part when developing products that is in collaboration with the human body. Human factors related tasks have an extensive need of using mock-ups for designing products with good ergonomics.

-VERIFICATION ON MOCK-UPS

It has emerged from the interviews that the majority has a unified picture that every aspect can be verified from mock-ups, depending which properties the mock-up holds. Verification can be done on system level as well as on component level. From the project perspective, the progress of the project can be verified and if certain requirements are fulfilled or not. Verification can also be done by having the possibility of comparing certain properties on a mock-up with customer needs.

The ILS department demonstrated the need of having the possibility to early verify the manufacturability in collaboration with the design engineer. Other aspects that appeared were verification on usability, reachability, aesthetics and semantics.

-AREAS WITH LARGER NEEDS OF MOCK-UPS

It has emerged from one interview with a senior project leader that new products, large and complex systems, on system-level, rack and components, equipment and interiors, connection units and intensively packed products are considered to be of importance for the company.

Some observations indicate that high risk projects are to benefit much from the use of mock-ups throughout the development process. High risk in projects can be due to the use of new technique, development of products with high uncertainty, when having many departments involved where there is a need of high coordination.

-ACCURACY ON MOCK-UPS

There is a need of having correct measures but not on a detail level, though enough accuracy for testing the intended property. The mock-up can be rough in the beginning and evolve during the project. There is often a need of having similar material properties in order to be able to use the mock-up. One of the design engineers states that it is enough to have centimetre accuracy, maximum and minimum dimensions on the mock-up.

Another engineer that was interviewed says that the mock-up needs to have enough accuracy to provide understanding for the customer. However, there is a consolidated view that the mock-up has less accuracy than the real product.

-SCALABILITY ON MOCK-UPS

Scaling is not appropriate for mock-ups with human machine interface purpose such as ergonomics, reachability and accessibility. It can be an alternative if full-scale is not possible or, as a complement to full-scale prototypes.

Areas for applying scaled mock-ups can be when trying different loading cases and when checking interface between components. Scaling could also be appropriate when evaluating concepts and in early stages of the product development process.

- MANUFACTURING TIME FOR MOCK-UPS

Needs to be finalised to a certain level early but mock-ups on system-level can be developed throughout the project. One of the design engineers states that it should take approximately 2 days when manufacturing simpler mock-ups. It is highly important to find out when the mock-up does not add more value for the development of the product.

-PREFERABLE MATERIALS TO USE FOR MOCK-UPS

Cardboard, foamboard, wood, styrofoam, and aluminium is considered to be appropriate materials. It is also stated from the interviews that it is enough to have materials that have accurate material properties compared to the sharp product. When evaluating the product in collaboration with the human body it should have enough robustness to allow the interaction. Though, from one interview it is stated that it is important that the mock-ups look realistic.

IMPORTANT QUOTES FROM EXTERNAL INTERVIEWS

In combination with internal interviews, three other organisations have been interviewed in order to get useful information from existing prototyping processes that are established and well-functioning.

Husqvarna group

Husqvarna group is the world's largest producer of outdoor power products which is constructed both for professional and consumers. The company is also the European leader within watering products for consumers and one of the leading companies of professional cutting equipment and diamond tools for construction industry.

Husqvarna group has a well-established process for manufacturing mock-ups that is included in their product development process. One of the departments, called Concept & Features which work as a pre-cursor stage to the ordinary product development uses simpler prototypes as a powerful development tool. Within Concept & Features the development of new products starts as soon as possible and as simple as possible. This work can be conducted with use of technique lego for evaluating ideas, concepts and designs. Later in the process, simpler prototypes is used in combination with existing products when developing add-ons or improvements of existing products.

Manufacturing of prototypes is often made in rapid prototyping machines which are seen as a simple and cost effective manufacturing method for prototypes. One of the drawbacks described by Husqvarna group is that rapid prototyping machines, sometimes make it to easy to manufacture physical models, which often leads to many errors because of lacking reviews on CAD-models.

Saab Training Systems

Saab Training Systems is a part within the Saab group which develop products to provide training solutions. The product portfolio is extending from virtual platforms to live training equipment that is used in combination with existing warfare products.

Saab Training Systems uses rapid prototyping machines in combination with manufactured parts from their engineering workshop. Stated from the interview is that almost every part is manufactured one time in rapid prototyping machines during the product development process.

When a design engineer order manufacturing of a prototype there is a pre-set paper to fill in and there is a close cooperation between the design engineer and workshop. One of the factors to establish a close collaboration is to have the workshop in close distance to design engineers. Thus promote cooperation and shortens lead-times when there is a need of change.

Saab EDS in Jönköping

Saab EDS in Jönköping is closely connected to Saab EDS in Gothenburg but due to different locations there is some difference in contexture and working procedures within the development of products. As well there are some small differences in resources for building prototypes. There is a more prepared working procedure for prototype construction and a more extensive use of prototypes compared to Saab EDS in Gothenburg. Recently, a new prototyping process was developed in order to decrease the fuzziness regarding prototyping usage and to increase the efficiency. Other improvements for the efficiency are to make it as simple as possible, as long as the purpose is fulfilled. Physical mock-ups and prototypes are much used in cooperation with the project structure, e.g. as project milestones.

Saab EDS Jönköping has listed three different purposes of using prototypes during their product development process:

- To early evaluate design ideas with intention to ensure that solutions meet the desired functional requirements.
- To minimise the risk of late changes in the product life-cycle which then is associated with a higher cost.
- To early validate requirements by the company and the customer.

There are also some risks associated when using prototypes in a product development project. Saab EDS Jönköping has identified the following risks if the use of prototypes is not defined and controlled:

- Project plans may not be followed correctly
- Internal milestones may be performed at the wrong time
- Feedback may be missed from some departments
- Experiences from prototyping may not be taken care of (no learning is occurring between prototyping cycles)

In order for the organisation to achieve a uniform definition of the different prototypes three different classes of prototypes are stated:

- *Installation/MMI prototype:* This prototype is used to evaluate a special part of the product e.g. airflow or installation. It can also be a computer program for evaluating the interface towards the user (MMI).

- *Assessment prototype:* The assessment prototype is used for early evaluation of design solutions, often through informal design test. The aim is to produce this type of prototype with a minimal amount of resources. There are no requirements for documenting this prototype, however the results from the evaluation using this prototypes should be documented and available during the later stages of development.

- *Functional prototypes:* These prototypes are divided into two classes; A-models and B-models. The A-models are to be used for testing and evaluation, both by the customer and internally and can be partial or fully functional. The B-models are to be built and verified according to the customer specifications. The only deviance from the actual product is the possibility for the prototype to lack environmental capabilities.

SUMMARY EMPIRICAL FINDINGS

The product development process at Saab EDS is comprehensive and complex as a result of the products that are developed. Several departments are involved and the product development is conducted in a number of sub-projects when designing the systems. This creates an extensive need for communication and coordination throughout the development process in order to satisfy the need of all involved departments.

The usage of prototypes at Saab is focused at producing comprehensive prototypes late in the process. The early, simple prototypes (mock-ups) are not utilized very often as a result of different reason connected to the early stages of the product development process.

The definition of the different kinds of prototypes used within Saab has to some extent an arbitrary definition. The expression “prototype” is the definition that is most agreed upon regarding for example usage and similarity to the product. The simpler prototypes (mock-ups and FUM:s) has a more arbitrary definition with almost one unique definition from each people within the organisation.

5. ANALYSIS

The information provided in this chapter is the analysis of the empirical data merged together with the theory from relevant literature. The product development and the projects which it is conducted in will be analysed initially. It will be followed by an analysis over how prototypes can affect the product development conducted by Saab and finally there will be an analysis around why mock-ups are not used today.

The systems that Saab is developing are highly complex. The products consist of several sub-systems which are individually very complex. Since each sub-system is developed by a specific department, this contributes to increasing the numbers of departments involved.

The customers have very specific and high demands on how the product should perform. This is causing the product development process to have extensive and elaborated testing and verification stages in order to capture eventual errors before the product is released. Since these errors still might be captured, they have an associated cost which is increasing when they are not corrected until late in the development process.

At Saab today there are a number of different kinds of projects conducted depending on what is to be developed. These can be compared to the different project types stated by Wheelwright & Clark (1992). Advanced development projects, platform projects and incremental or derivative projects can be compared to the projects identified on Saab: Research and development projects, next generation products and upgrades or add-ons. Noticeable is that Saab only conducts projects for next generation products every 10-15 years. Within Saab there is an additional project type identified not mentioned in the literature which is called "custom-made product" projects.

A great number of Saabs development projects are this type of customised products from their ordinary product family. Since the customer has very specific demands on the system, Saab seldom sell a product which is of standard design, regarding both hardware and software. Since much of the product development is conducted in these direct projects against the customer an extensive focus lies within the perspective of the project and not necessary on the product perspective. Each project has limitations in both time and money and extensive focus lies within making these profitable, which results in a lack of focus on developing superior products over time.

Different projects have different characteristics and with certain properties which are important to achieve throughout the development project. The advanced development projects will require deep knowledge and specialisation in order to achieve superior performance. These characteristics can be identified in the functional structure mentioned by several authors, which indicates that this way of organising can be beneficial in this type of projects. On the other hand when developing a platform or next generation products much focus is on achieving superior system solution and the integration of different sub-system. These characteristics can be identified in the organisations which are more oriented towards the project organisation, e.g. the heavyweight team structure mentioned by (Wheelwright & Clark, 1992). However at Saab there are no guidelines stated of how to work in different project organisations depending on what type of project to be conducted. This means that certain characteristics needed within a project to be provided by the specific type of project organisation needs to be solved by other means.

The market where Saab is acting is a relatively mature market. The market maturity can be a factor that will affect the uncertainty that is associated with product development. There are certain factors affecting why the market can be considered to have relatively low uncertainty:

- The threshold of technology is high. The technology which the radar is built upon and its system is very complex. This will make it difficult for new companies to enter the market and increase the competition.

- The technology which is used in the radars is relatively stable and not evolving very fast.

However there also exist factors which contribute to increasing the uncertainty associated with product development. One example can be that the product development time is relatively long and the negotiation process for selling a product can be several years. Since the process is this extensive there is a substantial possibility that demands and requirements from the customers can change during the time from initiation to delivery of the product. This is referred to as the challenge of dynamic associated with product development, stated by Eppinger & Ulrich (2012), when demands of the customer are changing. This makes it important to have a continuous communication with the customer in order to capture if demands and requirements are changing during the development.

PROJECT ORGANISATION AT SAAB EDS

Saab has organised their product development projects according to what is referred to as a matrix organisation by (Maylor, 2010). Wheelwright & Clark (1992) states two orientations of such a matrix organisation, the heavyweight team structure and the lightweight structure. Saabs way of organising resembles these both structures but has an overweight towards the lightweight team structure. The different project team members resign in their different functions, however within each department or function the team members co-locate depending on which project they belong to. The project manager is often a very senior person within the organisation which can be compared to the heavyweight project manager more than the lightweight manager. In addition, the project manager has the ultimate responsibility for the project with for e.g. budget, time-schedule and direct contact with the customer. In comparison to the heavyweight, the project manager in a lightweight team structure usually has little status or influence in the organisation. Though usually possess considerable good expertise and experience from working within some functions earlier which can in these aspects be compared to the project leaders within the Saab organisation. Though Wheelwright & Clark (1992) states that typically the project managers spend no more than 25 percent on a single project which differs from the approach at Saab where the project leaders spend 100 percent on one project. This depends on that almost every project is very extensive and range over several years which therefore require full allocation to a specific project.

Even if the project manager is heavyweight the project organisation has strong links to the functional structure. The transfer of responsibility within the functional organisation referred to in the literature as “throwing it over the wall” by Wheelwright & Clark (1992), can be identified also in the Saab way of working. Examples of this can be when the product transfers from P-mode into R-mode and manufacturing department takes over the responsibility from the design department. The effect is that problems often arise when products are transferred between functions. This is also stated by the production planner who states that “there are often problems with products when they arrive to us”. The fundamental issue to resolve this will be to ensure that communication takes part between functions throughout the product development, something stated by McGrath (1996) as one important characteristic of successful project teams. There is a wish from different departments at Saab to be involved earlier in the product development process, for example an engineer at the ILS department states that it is “important to be involved early in the process because it becomes harder to change thing as the development work progress" (compare to figure 7). This suggests that there is a need for improving the framework for communication across different functions.

Since Saab is developing highly complex products with many departments involved throughout the development process, there will be an extensive need for communication (McGrath, 1996). This is also supported by Malmgren & Ragnarsson (2001) who states that in advanced and very complex product development projects there is an extensive need for communication and collaboration. If the project organisation does not provide and support for cross-functional communication this has to be achieved by other means. One important tool that can aid communication throughout the product development is the use of prototypes (Liou, 2008). This is also identified as one of the needs and purposes of using different kinds of prototypes at Saab, stated by many engineers from different departments.

Prototypes are a tool that in many different ways can aid the product development process. Traditionally a company with high technical risk and high cost of comprehensive prototypes manufacture one or few comprehensive prototypes seen in figure 10. This behaviour can also be identified at Saab, the advanced technology within a radar system can be considered to have high technical risk, and their cost of building a comprehensive prototype is high. Since there is only one or a few prototypes built during a product development, the logic behaviour would be to increase the usage of simpler prototypes e.g. mock-ups during the product development to fully benefit from this tool. However this type of simpler prototypes is seldom used as stated before.

Wheelwright & Clark (1992) states as one of their suggestions for improving the prototyping process to increase the representativeness of the early prototypes. The early prototypes e.g. simple industrial design models are often less expensive than pre-production prototypes. By increasing the representativeness of the early prototypes these can contribute in a greater extent to the development process and in some dimensions ease the use of later prototypes. This can be applicable for a company such as Saab when developing complex systems and comprehensive prototypes which are expensive. If certain properties can be tested with simpler and cheaper models they should be considered. Regarding the early prototypes used for communication with customers, Liou (2008) suggests that simple prototypes or mock-ups better fulfil the purpose of eliciting feedback from the customer than high quality prototypes. By using simpler prototypes with fewer details the customer can focus more on feedback regarding the fundamentals of the concept than colours, labels or graphical details.

One type of mock-ups mentioned from the interviews at Saab are the mock-ups used for packability studies, which for example test if a given space for a component is sufficient (Johansson, Råberg & Killander, 1996). By using the cheaper mock-ups for the packability studies this can be verified in a cheaper way than with the more expensive prototypes and used as mentioned by Wheelwright & Clark (1992) above.

DIFFERENT PROTOTYPING STRATEGIES

Depending on what type of development project that is conducted different type of strategies for using prototypes can be beneficial (Wheelwright & Clark, 1992). Since there do not exists any used process or method within Saab of how to use prototypes there is a lack of different focus on how to conduct prototyping with different strategies depending on type of project.

There is however one example appeared from the interviews where using a different strategy can be identified within Saab. When a new product was to be developed, the product management required that a large-scale mock-up was to be build. This mock-up was built during the initial stage of the concept design phase. The product was to be developed with a new kind of solution on system-level which required extensive communication across departments and the different functions. To achieve a superior system solution a number of workshops were held with the different involved functions and departments. By comparing this to the model suggested by Wheelwright & Clark (1992), the project can be identified as a new platform product and the prototyping can be compared somewhat to the "periodic prototyping program". The prototypes was not used in cooperation with milestones as intended by the authors from the literature, but the extensive focus on achieving a superior system solution with clear integration can be identified. A lot of time and effort was invested in this mock-up which is contradicting to what several authors who suggest that early prototypes should be rapid support decisions about feasibility Gebhardt (2003), (Barkan & Iansiti,1993). The explanation might come from for example size and complexity of the system which requires more time to build as in the case of a mock-up on system-level, even if the mock-up is rough and built at the concept stage. This method of working with simpler prototypes has been perceived very positive by involved departments and great benefits has been created.

On the next page is a figure from Wheelwright & Clark (1992) which describes the progression of prototypes cycles. The figure 16 on the next page can be connected to Saabs way of working from concept to final product and the different levels on the y-axis also reflect the decomposition from the overall system to components that is used in the organisation for the product development process. Wheelwright & Clark (1992) describes that design- build- test cycles should be first used on system level and further cycles is primarily made by engineers on sub-system and component level. Management can effectively use prototyping cycles to easy lead and pace the development work and to track progress, allocate resources and be able to address issues in an early stage. Above approach can be fully utilised at Saab by starting to use simpler prototypes (mock-ups) throughout the project and address different issues with different prototypes and be able to focus the work on relevant problems.

The V-model used by Saab for planning the verification of the product can be compared to this described method. By using more prototypes verification can start earlier and later recognised errors can be reduced. It will however be important with communication between the responsible for the prototype and the department of verification in order to create prototypes most effective that can be used for verification in addition to the original purpose.

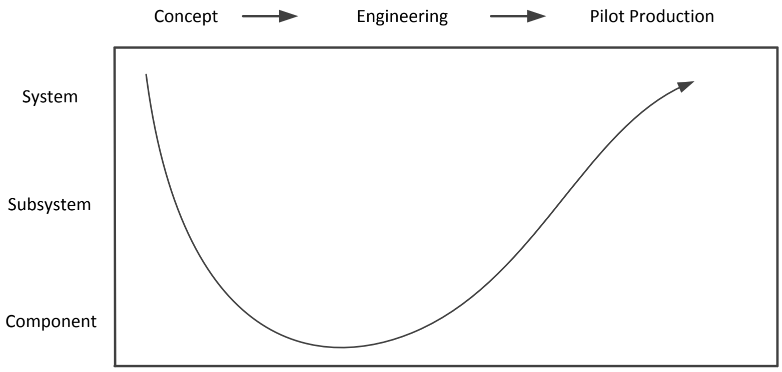

FIGURE 16 PROGRESSION OF PROTOTYPES CYCLES

HOW PROTOTYPES AFFECT THE STAGE-GATE PROCESS

The development process at Saab has many similarities with the traditional stage-gate process stated by (Cooper, 1990). For example the part of the process used by the mechanical department (figure 13) resembles the stage-gate model to great extent. The technical reviews and the design reviews are typical gates where certain criteria need to be fulfilled in order to proceed to the next stage and the work is conducted between them in the stages of e.g. conceptual design and physical design.

Since the technical reviews are focusing to great extent on the technical solutions of the part or sub-system, this is the gate that could benefit most from a more frequent use of prototypes. These reviews are most often conducted with help of the 3D-CAD programs where the different gatekeepers review the virtual model. Both people within the organisation of Saab and parts of the literature describe problems with having these types of reviews. One engineer from Saab states that people tend to comment more when evaluating something physical than a virtual model. One reason for this can be that people not used to working in CAD environment can have difficulties providing creative feedback when studying these. Similar is stated by Gebhardt (2003), that for example people from management and marketing can have a hard time understanding, or fully understand, a technical drawing.

By the use of more prototypes in cooperation with the gates more rational decisions can be made. People attending the gate-meeting will be able to provide more creative feedback to the design engineer and fewer mistakes will pass the gates unnoticed.

In addition to using the prototypes within the stage-gate framework, prototypes can be used in cooperation with the project framework. A suggestion for usage in cooperation with the project framework can be of using prototypes as milestones (Wheelwright & Clark, 1992). This has also been expressed as a method of using prototypes (and simpler prototypes, mock-ups) on interviews at Saab. As milestones, prototypes will be physical evidence that the project has reached certain progress and will be easier to evaluate for management and project leaders. Eppinger & Ulrich (2012) states that later prototypes is used most beneficial as milestones. This since later prototypes is used for verification as opposed to early prototypes which are used for testing. When a prototype can be used for verification, certain project progress can be stated and hence more suited to integrate as a milestone.

PROTOTYPING IN THE FUZZY-FRONT[3] END

Projects suffer to a great extent from different sources of uncertainty. The uncertainty is as shown from a number of authors at its maximum in the beginning of the project (Verganti, 1999). Saab has as analysed above uncertainty in some dimensions connected to the product development. To reduce the initial uncertainty it will be important that the project team embrace early and rapid learning. Barkan & Iansiti (1993) states that each prototyping cycle provides a learning experience for the entire project team, which consequently will contribute to reduce the initial uncertainty. Early tests with even rough prototypes can contribute to reducing the risks associated with innovation.

LEARNING AND PROTOTYPING

Prototypes are an excellent tool for capture and enhancing knowledge in an organisation when developing products (Wheelwright & Clark, 1992). Since Saab do not have any used process or unified method of working with prototypes it is difficult for learning to occur. Wheelwright & Clark (1992) states that systematic study of the types of problems that can and should be solved in each prototyping cycle during the development work can help identify new ways to plan and realise the prototyping cycles. When not working with a stated prototyping process, engineers who are going to develop a prototype starts from the beginning every time, they can indeed accumulate knowledge themselves, but there will be no systematic knowledge transfer from one project to another.

PROTOTYPING FROM A PROCESS PERSPECTIVE

If analysing the work conducted with prototypes compared to the process perspective presented in the theory chapter following result can be obtained.

The prototyping process is a supporting process to the product development process which is one of the core processes within a company. The following input, transformation and output can be identified when a prototype is developed through the prototyping process:

Input: The input into the prototyping process is the need which can be connected to the different purposes of using a prototype. There can be a need for increased communication or rapid learning.

Transformation: The transformation is the part of the process where the input is transformed into the output. In the case of prototyping the transformations consists of planning the prototypes (depending on the input), building and finally testing and verifying the prototype.

Output: The output from the transformation process can be seen as the learning from the specific test and verification on the prototype or the learning from feedback gained from the communication with the customer.

[3] The fuzzy-front end is referred to as the initial phase of an innovative product development project (Kurkkio, 2011)

The usage of different prototypes at Saab today is almost exclusively focused on producing one prototype within each project which to great extent resembles the product. There are several cases where the prototype has been produced with same properties as the intended product and been approved in all verification stages. Therefore prototypes has sometimes been delivered to the customer as the sold product. This has also been conceivable due to that developed products at Saab are of low-series and production method and ramp-up time is of less importance, as a consequence the product development cost for each product are very high in comparison to the production cost. Different kind of Functional models (FUM) are also used to test certain functionality where verification is needed to ensure the performance of the product.

Questions connected to mock-ups asked during the interviews along with the provided answers are analysed and categorised into different general areas. These areas are presented below and a complete presentation can be seen in appendix III:

- *PROJECT FRAMEWORK*
- *FUNCTION AND INTEGRATION*
- *DESIGN AND ARRANGEMENTS*
- *COMMUNICATION*
- *HUMAN FACTORS*

The different areas can be seen as the different purposes of using prototypes. These can be compared with the different purposes stated by Eppinger & Ullrich (2012) which are milestone, communication, learning and integration. The project framework can be compared to the purpose of milestones where the need is to show project progress. The purpose of integration and learning can be compared to the area of function and integration where the focus is to learn more about functions and solutions but also how different parts can be integrated with each other. Design and arrangements can be compared with the purpose of learning and communication since prototypes is used for learning and communicating regarding for example serviceability and space needed for a particular component. The communicating part can for example be needed feedback from the departments that works with service on the products. The area of human factors can be compared to learning since there is a need for an increased focus on these questions when developing products that interacts with the human body. This type of products have traditionally not had an extensive focus on human factors when being developed.

Reasons for not making mock-ups

The simpler prototypes, often called mock-ups, are seldom used. Within Saab there are many reasons mentioned why these are not utilised, even though the overall benefits of using them are well known. The different statements from the interviews regarding this has been analysed and sorted into different identified problem areas. These areas are shown on the next page in figure 17 and can also be found in appendix IV.

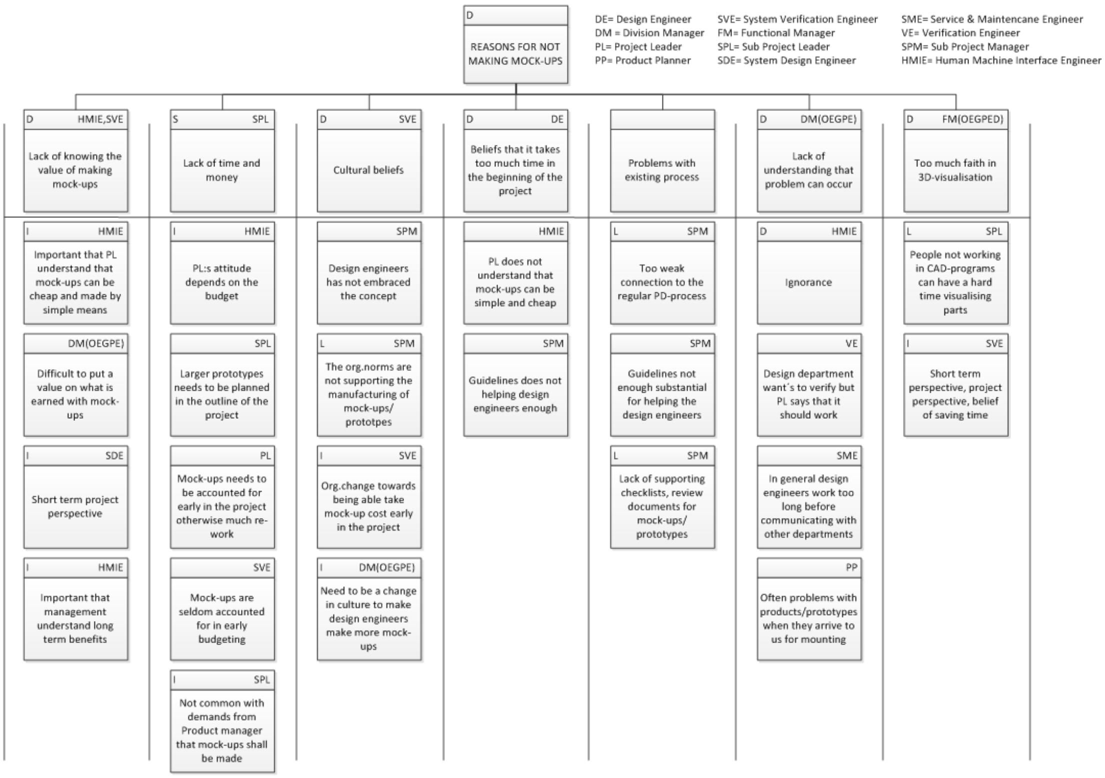

FIGURE 17 IDENTIFIED PROBLEM AREAS WITHIN THE REASONS FOR NOT USING MOCK-UPS AT SAAB EDS IN GOTHENBURG

What can be seen from the different statements from the interviews is that people have a rather unified view of the reasons for not making mock-ups. From the analysis there exist mainly seven different problem areas which are described below:

THE LACK OF KNOWING THE VALUE OF MAKING MOCK-UPS: One of the main reasons for not knowing the value of using mock-ups is considered to be connected to having a low experience of mock-ups and knowing that it is a valuable tool in product development. By having a low experience from mock-ups it will contribute to not knowing where in the PD-process to use the mock-ups and how to use the mock-up in a beneficial way. Since it is also difficult to estimate the actual value with using mock-ups as a tool in the development process compared to excluding mock-ups, it will be difficult to motivate the use. It will also be difficult to estimate the actual cost-saving on a change that is not needed due to that mock-ups are used early in the product development process.

LACK OF TIME AND MONEY: Since most development within Saab is made in projects, it is vital for the prototyping process that mock-ups are planned in the outline of each project. Eppinger & Ulrich (2012) states that a plan should be made for how to use prototypes in the development of products and suggest a four step method to use in order to ensure that prototypes contribute to the overall goal. Liou (2008) presents a similar method which is a more detailed planning, concentrated on time and cost. By establishing a plan at Saab that includes the manufacturing of mock-ups it will contribute to the overall efficiency in the product development process since it will force the people to see the benefits and use simpler prototypes more frequent. The main reason for using mock-ups is to contribute to an efficient product development process and this is strongly connected to reducing the cost which is connected to the time consumption. Therefore, to change the belief of having a lack of time and money within projects it will be important to solve the issue where it has its origin. The origin is considered to be in the outline of the project and a plan which includes mock-ups will be to solve the issue before it has been raised.

CULTURAL BELIEFS: McGrath (1996) writes about change behaviour and presents a list of why an organisation is resistant to change. One of the reasons is considered to be that improvements usually require a change in cultural beliefs which can somehow be linked to the organisation at Saab. People within Saab often have great experience from the existing process and have a great routine in their work. Changing people ways of working involves great uncertainty and people often react with reservation (Rubenowitz ,2004), which demonstrates the difficulties for change within the organisation. At Saab, management plays a vital role for making these improvements by encourage and motivate the change in order to penetrate and overcome the threshold to change the setting from people in the organisation.

BELIEFS THAT IT TAKES TOO MUCH TIME IN THE BEGINNING OF THE PROJECT: Product development within the organisation involves at least one prototype which is manufactured as a sharp product with small deviations. In the literature, prototypes are seen as a helpful tool throughout the product development and include many different types of prototypes. Eppinger & Ulrich (2012) defines a prototype as an approximation of the product on at least one aspect. To change the belief within Saab there is a need to change the view of prototypes of something that is used late in the product development and demonstrate that prototypes can be simple mock-ups that verify a certain aspect in an early stage. From interviews it also emerges that there is a need to define and divide prototypes in different classifications. By defining mock-ups and demonstrate that these type of prototypes can be used in an early stage and manufactured by small efforts, mock-ups can contribute to a change in the believe that it takes too much time in the beginning of projects when using prototypes. This is confirmed in the literature from Gebhardt (2003) which states that simpler prototypes used in the beginning to evaluate a product idea will result in a faster and more effective product development process.

PROBLEMS WITH EXISTING PROTOTYPE PROCESS: The existing process is seen to have a weak connection to the existing product development process and supporting documents are not enough to support the process. To encourage the use of a process or method, the process needs to simplify the work to be conducted and be a support in the development of products. In order to simplify the work, a strong connection to the product development process can be vital. If a prototyping process could be fully implemented into the existing product development process it could be seen as prototypes would be standard in the development process instead of an option that could be used if needs arise.

LACK OF UNDERSTANDING THAT PROBLEMS CAN OCCUR: It arises from the interviews that people are ignorant and that people working with their own tasks takes too long before starting to communicate with other involved departments. One of the reasons of this behaviour can probably be connected to the products developed at Saab. The products produced by Saab are complex and contain high-technology. The consequence is a large organisation with need of much communication and the physical distance between people will furthermore disfavour the communication.

TOO MUCH FAITH IN 3D-VISUALISATION: One of the most powerful product development tools is considered to be CAD-programs which enable the possibility to construct drawings and visually present products in an effective way. Every development project at Saab consists of much 3D-visualisation and there is a great faith among the design engineers in these programs. Technical reviews (TRW) and Design reviews (DR) are conducted with the help of CAD-programs and could probably benefit from using the reviews in combination with a physical prototype. Eppinger & Ulrich (2012) states that the communication with involved people will benefit from the use of a physical prototype to enable an easier understanding and to give a feeling for the product. From one interview it is stated that people not working in CAD-programs can have a hard time visualising parts which indicates that more prototypes would be beneficial.

It emerges from interviews that it often occurs problems and deviations between the CAD-models and the product when it comes to assembling. Something designed in CAD can be perfectly designed but will not work in reality due to a dynamic environment and other factors. For e.g. Cables will not act exactly the same in reality in comparison to the CAD-design and it is very hard to analyse how to assemble in a favourable way without using prototypes.

Coupling of problem areas

The different areas that has emerged from the interviews and analysed above can be seen to have some interconnection between each other and this will be presented below and should be read in combination with figure 18.

The reason for excluding mock-ups in the product development process could have its origin from the lack of understanding that problem can occur and that there is too much faith in 3D-visualisation. These two areas can be seen as cultural beliefs within the organisation. By having these cultural beliefs on prototypes in the organisation, people would not use the existing prototype documents because not seeing the value of using these simpler prototypes. On the other hand it could also be that people have a lack of understanding the value of mock-ups due to that the existing prototype process is not frequently used. By not knowing the value within prototypes and that there is a lack of having a good process people might believe that it only takes too much time in the beginning of the projects. Finally this leads to that people believe themselves having a lack of time and money.

By ending up in the belief of having a lack of time and money can also be seen as a main reason for not making mock-ups but all the above presented interconnections between areas of problems can be seen as a vicious circle. This vicious circle can be solved by breaking the pattern, which is to solve the origin problems that arise from the cultural beliefs.

Barkan & Iansiti (1993) states that using prototyping early in the development process minimises the effects of late changes. Consequently not using prototypes can increase the need for time and resources needed for late changes. At Saab, when believing of having lack of time and money, this can be a result from earlier project with late changes when prototypes were not used in the early stage.

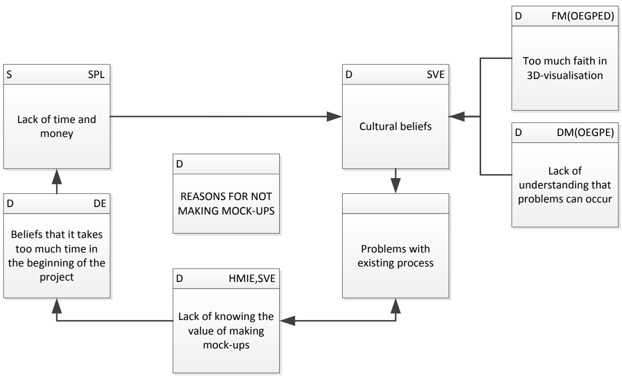

FIGURE 18 INTERCONNECTIONS BETWEEN PROBLEM AREAS

DEFINITIONS OF PROTOTYPES

Prototypes include a wide spectrum of different properties depending on people's perception which appear from interviews performed both internally and externally. To be able to encourage the use of prototypes in the product development process it is important that the company has a unified picture of prototypes. There is a need for the company to use a classification of different prototypes due to that there is an overall belief that prototypes is something extensive and used late in the process and which require much effort. By using a useful classification of prototypes at Saab EDS in Gothenburg and define different prototypes according to their properties it can be demonstrated that different prototypes can be very useful in different stages in the product development process.

From existing prototype documents at Saab EDS there is a brief classification of different prototypes made. The classification is made to clarify and to show the difference from each prototype. Saab EDS in Gothenburg uses three different classes: Mock-up, Functional model (FUM) and prototype which can be compared to Saab EDS in Jönköping which uses the classes of: mock-up/ MMI prototype, Assessment prototype and functional prototype. The functional prototype is divided into A and B-models. Connections can be drawn between mock-up/ MMI prototype, assessment prototype against the mock-up and Functional model used at Saab EDS in Gothenburg. There is however no clear distinction between these two areas. Prototype and functional prototypes corresponds to each other with the only difference that the functional prototypes are divided into A and B-models depending on the extent.

The A and B-models suggested by Saab EDS in Jönköping have a division according to; A-models refer to be used internally and by customer for early benchmarking against testing. The B-model should be used in internal or in customer test rigs for validation. The division could probably create confusion in the organisation since the division is not distinct divided and some prototypes can overlap between the models. However if there is a clear distinction between the models, it can create value to have the division since it mediates the properties and how the prototype should be used. At Saab EDS in Gothenburg the division for these advanced prototypes could be seen as redundant due to that the concept of prototypes at the company is well established and often manufactured for both purposes.

Gebhardt (2003) suggest a division as follows: Proportional model, ergonomic model, styling model, functional model and prototype. If comparing this with the other two divisions it corresponds best to the classification made at Saab EDS in Gothenburg. The only deviation is that both Proportional model, ergonomic model and styling model relates to mock-ups. Gebhardt (2003) also suggests a simplified classification for daily rapid prototyping. Using levels inside the different classes as used at Saab EDS in Jönköping can probably be useful in order to show certain properties for each model and what it can be used for. Having a very extensive verification can probably gain from having certain models that can verify certain properties and that the name is describing the properties of the model.

What can be seen from the interviews is that the classification made at Saab EDS in Gothenburg have not penetrated into the organisation and people sometimes uses an own classification and view on the definitions of simpler prototypes. The reason for this probably derives from the lack of using simpler prototypes.

6. RESULTS

The result delivered to Saab EDS in Gothenburg does mainly consist of three different documents. The suggested prototype process is supported by two documents that are used for documentation and as a support to the process. The total process developed for Saab is designed to have the possibility to be implemented into the existing MCD process and visualised in a virtual way similar to the existing processes. Below is an overall presentation of the documents and the complete documents can be found in Appendix VI, VII and VIII.

PROTOTYPE PROCESS

The prototype process consists of seven main steps, where every step consists of several sub-steps and presented below in figure 19 but also in appendix VI. The process should be seen as a flowchart and is designed to range from simple to comprehensive prototypes and if it is not necessary to use a step or sub-step it should be excluded.

The primary purpose of the prototype process delivered to Saab EDS is to encourage the use of prototypes and to establish guidelines to follow in order to demonstrate the ease of the process. The designed process is presupposed from what the literature suggests and is mapped against Saab EDS needs and modified to a great extent. This has created the possibility to implement the prototype into the existing product development process.

In general the prototype process consists of three key areas which is plan, execute and learn. This approach is supported by the theory and enables a process that ensures a continuously building of knowledge and increasing the quality of the prototyping process.

The process will satisfy the need of having a unified picture of how to manufacture prototypes within the company and be a supporting process to the existing product development process. The process supports an increased learning and contributes to a better usage of prototypes.

The first step of initial planning does mostly affect the project leader that makes the plan in the outline. In the outline it is highly important to consider the prototypes and decide on prototypes in cost estimations and allocate enough resources. This is vital for the prototypes in order to be a helpful tool in the product development process which is a reason for having this as an initial step in the prototype process. The initial planning for prototypes maximises the usage of prototypes and have the best effects on the development effort since enough pre-requisites is created early in each project.

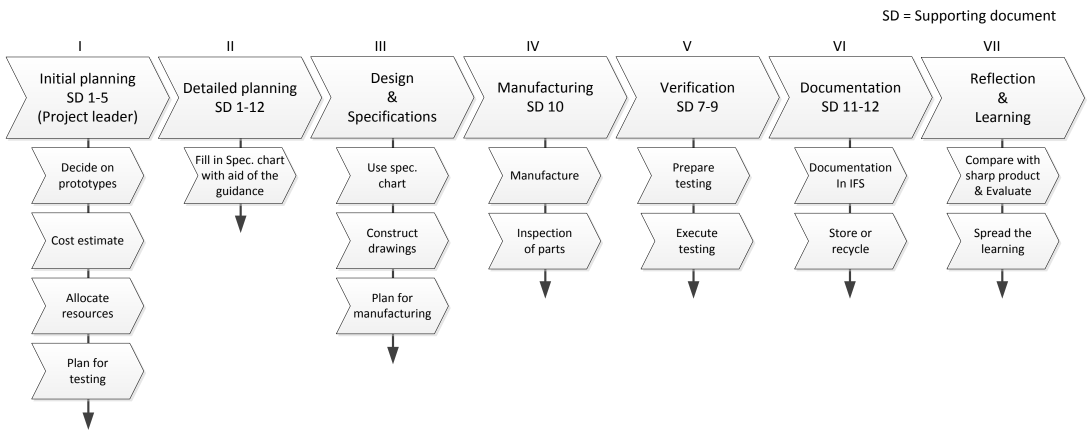

FIGURE 19 SUGGESTED PROTOTYPING PROCESS

PROTOTYPE GUIDANCE

The prototype guidance is to be seen as a supporting document to the prototype process and designed to highlight all relevant aspects to consider when using prototypes. The prototype guidance can also be seen as a tool that helps to understand the prototype process and make it possible to establish a useful prototype that meets all requirements. The outline of the guidance can be seen in figure 20 and can also be found in appendix VIII.

Every step inside the guidance should be considered in a chronological order from left to right. There are supporting documents (SD) connected to every step that is used to clarify and as a description of the different boxes.

Similarly to the prototype process, the prototype guidance is designed to cover all aspects connected to prototypes in order to be designed for both easy and advanced processes. Therefore steps or sub-steps that are not seen as important to consider can be excluded.

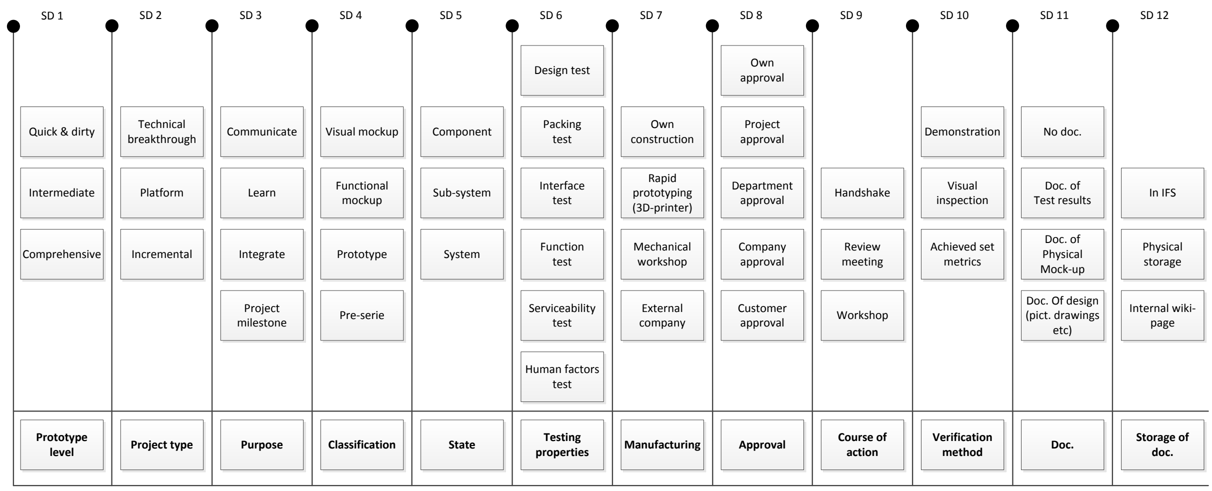

FIGURE 20 SUGGESTED PROTOTYPING GUIDANCE

SPECIFICATION CHART

The specification chart should be seen as a documentation tool to the prototype process and a document that is used throughout the process. It ensures that relevant factors are carefully considered. The specification chart is presented on the next page in figure 21 and can also be found in appendix VII.

The document is in close connection to the prototype guidance and the headings in the document correspond to the headings in the prototype guidance. The different supporting documents is also connected to each heading except from the time plan, demands & requirements and costs which will be unique for each prototype and used more as general information.

The documents can also be used for better communication possibilities by having an easy and rapid understanding of how comprehensive the prototype is. The use of the specification chart will also contribute to an easier knowledge transfer between prototypes.

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Date	Issue	Document ID
2013-04-23		

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Classification Company Confidentiality
COMPANY UNCLASSIFIED

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NOT EXPORT CONTROLLED

Classification Defence Secrecy
ÖPPEN/UNCLASSIFIED

Specification chart

Prototype level & Project type (SD 1-2):

CAD-Model/picture

Purpose (SD 3):

Classification & State (SD 4-5):

Testing Properties (SD 6):

Verification (SD 7-9):

Manufacturing and materials (SD 10):

Documentation (SD 11-12):

Time plan:

Demands and requirements:

Cost:

Potential risks:

IN 5000358-159 Issue 1

FIGURE 21 SUGGESTED SPECIFICATION CHART FOR PROTOTYPES

7. CONCLUSION

This section will describe the conclusions made in this master thesis. It starts with general answers connected to the research questions and it is followed by more detailed conclusions regarding prototyping at Saab EDS in Gothenburg and the different areas of the research questions.

The product development process is a difficult process which contains both complexity and great uncertainty. A product development project often contains efforts that cross through many functions within the organisation which require much coordination and communication. At the same time these projects has increasing pressure from time, cost, quality and increasing complexity within the products.

A very useful tool that aids the product development process is the use of prototypes. A prototype is a tool that can be used throughout the entire product development process. The use of prototypes can have many benefits. Examples of the use of prototypes are that they increase the communication between different stakeholders in the development project, reduce the risk for unforeseen changes late in the process and provide an opportunity for rapid learning early in the development project.

The research questions posted in the outline of this thesis work has been answered by the work conducted. Saab EDS works in present to some extent with prototypes but is focused on comprehensive prototypes used late in the development process. The classification is somehow arbitrary but the different definitions used are mock-up, FUM and prototype. There is a unified picture regarding the definition of a prototype but the definition of mock-up and FUM is more difficult to define explicitly. Therefore there is a need of a new classification and the new suggested classification which can be found in appendix VIII has its origin from the interviews and will provide a more beneficial and unified classification. Compared to the prototype usage at Saab EDS today there is a possibility to increase the efficiency of the product development process. This possibility comes from an increased usage of simpler prototypes such as mock-ups used early in the development process. The following sections in the conclusion will have a more detailed explanation of the different areas covered by the research questions.

A great number of Saabs development projects can be described as customised projects. Saabs different customers usually have very high and specific demands causing extensive modification to the ordinary product program which much resembles product development of new products in terms of resource consumption. This is one reason for the extensive focus on the specific project and not for developing superior products over time. This focus causes strong emphasis on both time and cost constraints within each project and creates a belief of not having the resources for building simpler prototypes early in the projects.

The prototypes developed by Saab are usually concentrated in the later stages of the development phases and focuses merely on verification. But since the systems are complex and comprehensive these prototypes become expensive. By an increased use of simpler prototypes the more advanced later prototypes can be used more effective and consequently something that would be beneficial for Saab. This need is also identified among people within several departments at Saab. This usage of prototypes corresponds to several sources in the literature which states that prototypes early in the development process should be of simpler kind.

From the interviews it was stated that the project managers need to include prototypes early in the process when money is allocated. If not included in the project budget it will be difficult to get approval for producing a prototype, it will therefore be important to make the project managers understand the benefits with mock-ups and understand that they can be cheap in relation to what benefits they bring. This suggests that the prototyping process initially should be used by the project leaders in order for design engineers to be able to develop the prototypes (figure 19).

There exist many reasons for mock-ups not being used at Saab today. There is an extensive faith in the CAD programs which are used to produce virtual 3D-models. The problem with these is that they are difficult to understand for someone not daily working with such a program. Among people there is also a belief that even mock-ups are extensive and time consuming to build, which contributes to not using them in the development work. In addition it is very difficult to quantify the value that mock-ups create since it is hard to put a price on the cost of an excluded late change on the product.

Within Saab there is not in general any common understanding regarding the classification of different prototypes. A fully functional prototype used late in the process has however a relatively common understanding regarding the definition, but mock-ups used earlier in the development process will have a more arbitrary definition. This can lead to misunderstandings between different departments about characteristics and what the prototype can be used for. It can also be more difficult to get approval for producing a specific prototype if there does not exist any common definition since the approver of the prototype might not understand the extent. The suggested classification for Saab has properties from both classifications mentioned in the literature and from external companies. But it is important to mention that different definitions vary to a great extent between different companies and industries, consequently has the new classification been mostly influenced by Saabs unique needs. The suggestion for classification has been iterated several times with key persons within the organisation in order to assure a useful classification. It is however difficult to introduce new denominations that will be used throughout the organisation. The classification suggested will be: Visual mock-up, functional mock-up, prototype and pre-serial. For a full description of the definitions, see appendix VIII.

The products that are developed by Saab are highly complex and advanced. With these characteristics on the products, the development process will be even more difficult. This will put high demands on communication and coordination throughout the project and an increased use of prototypes can aid the project in these issues. Increased communication can also be achieved by organising the development projects in teams with less connection to the functional structure and stronger links to the project team.

With the extensive development projects conducted by Saab that can have lead times up to 5 years means great uncertainty. There will be a need for communication with the customer during this time since there is an increasing possibility that demands and requirements change over time. By using the prototypes as a communication tool towards the customer more useful feedback can be gained.

The identified needs within the company regarding mock-ups can be mapped against purposes of using prototypes stated by several authors in the literature. When comparing these two it appears that the needs and different purposes coincide to a great extent. By clearly defining the developed prototypes by using different purposes this can substantially contribute to satisfying the needs from different departments.

The development process at Saab resembles to great extent a typical stage-gate process. Within the gates where taking the go/no-go decisions, prototypes can be a great aid since people tend to easier understand a physical item than something visualised by the aid of a virtual CAD-program. By providing the people who attends these gates the possibility to give creative feedback, possible errors can be captured earlier in the process saving both money and time.

If Saab establishes a process for the development of prototypes several benefits can be gained. A very important benefit can be an increased possibility to achieve a continuous learning regarding the development of prototypes. By having a uniform way of working it will be easier to transfer knowledge between different prototyping cycles. If learning can occur prototypes can be produced more efficiently and aid to that the product development process becomes more qualitatively. This has contributed to having the last step in the process consisting of the learning aspect. An explicit step in the process does not assure a continuous learning but will increase the probability that it will be considered by people within the organisation building prototypes.

The suggested process will satisfy the need of having a unified picture of how to manufacture prototypes within the company and be a supporting process to the existing product development process. The process supports an increased learning and contributes to a better usage of prototypes. The general process is visualised below in figure 22.

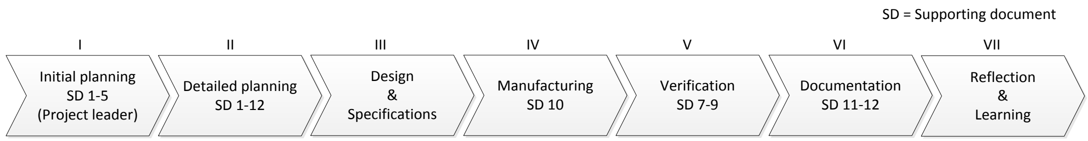

FIGURE 22 SUGGESTED OVERALL PROTOTYPE PROCESS

The process used for developing prototypes needs to be simple and easy to use. In addition it needs to have a clear and strong link to the product development process. There was a lack of these two factors before and this was contributing to the low and unstructured usage of mock-ups.

The overall conclusion of this master thesis is that there is a clear strategy of prototyping to follow for Saab EDS in Gothenburg in order to increase the overall efficiency of the product development process. The strategy involves an increased usage of simpler prototypes (mock-ups), a unified definition of the different prototypes and a commonly used prototyping process.

8. DISCUSSION

Since the usage of late and comprehensive prototypes is firmly established in the organisation, there is a clear definition of the purpose and how they are used. Simpler prototypes that shall be used early in the product development process will have a more arbitrary definition. This can also be recognised at external companies visited and the revised literature. Depending on the industry or the specific usage, definitions of simpler prototypes tend to diverge. As in the case recognised at Saab, more complex prototypes with higher similarity to the product will be converging to a more common definition. Therefore it might be more of importance to choose a classification that fit the organisation and fulfil the specific purpose or needs rather than using existing classifications that are optimised for another organisation.

The compilation of the interviews that was later analysed and divided into different areas can be seen to have a strong connection to the different purposes of prototyping described by several authors. Elicited from the compiled interviews is that a more frequent use of simpler prototypes can have positive effects throughout the product development process and contribute to an overall improvement. One of the most important purposes of prototyping elicited from interviews seems to be the communication. This derives from the extensive need of communication between departments within the company and the misinterpretations connected to the communication.

A useful prototyping process used in combination with the existing product development process needs to be easy and user friendly to encourage the usage, this in order to increase the possibility of people to start using it. The connection between the processes should be strong and clear. This emerges from that the earlier guidelines had a weak connection towards the development process and could be one reason for the non-frequent use.

As derived from the analysis, the low frequency of using mock-ups can be composed from several different sources. The correct usage of simpler prototypes will aid the product development but an incorrect usage will only be time consuming and costly. It is difficult to argue that mock-ups will aid the product development process due to that it is difficult to estimate the value of using simpler prototypes compared to excluding it. This demonstrates that in order to establishing a more frequent use of simpler prototypes in the organisation there is a need of having a previous positive experience from prototyping.

The case study method used in this master thesis was relevant to use since there was a need of a comparison between the relevant literature and the company's view and needs of prototypes. Among the sources of information, documentation and interviews has been most frequently used. The range of relevant literature connected to prototyping has been relatively hard to gather, since the supply appears to be limited. Though, enough information has been collected in order to conduct a relevant thesis work around the chosen topic. The used method has included an additional step which involves iteration after the first conclusion has been taken. This has been included to ensure a process suggestion that satisfy both the unspoken and spoken needs.

The focus within the conducted interviews has been regarding simpler prototypes. This since Saab with their specific products and development process would have much to gain from an increased use of these. It is possible that the usage of more extensive prototypes could benefit from a deeper analysis but this has not been within the scope of this project.

It is relevant to consider the choice of people that were interviewed. Depending on who is interviewed the answers to the questions might somehow differ. The people chosen aimed to cover all relevant aspects around the chosen topic and were selected in cooperation with people familiar with the organisation. The number of interviews conducted within the organisation was somehow limited but saturation of the received answers was still noticed. This suggests that more interviews would not create any more value to the work conducted.

The process mapping method mentioned in the method section has been used in general. All included steps have not been followed as intended by the author since some steps are difficult to conduct because there is a lack of a unified working method. Existing documents concerning work regarding simpler prototypes should be seen more as guidelines than a process to follow and has a weak link to the existing product development process. The weak link to the development process might be a substantial factor why it is not frequently used.

The recommendations given by the suggested process has been evaluated by a steering committee connected to the project. People represented in the steering committee consisted of a number of people from different departments and with different experience. Much useful feedback has emerged from meetings and occasions when the suggested process has been discussed. However, as in the case of Saab with a large organisation certain aspects might be overseen, interesting for not involved departments. But the developed prototyping process is mainly developed to meet the requirements from the mechanical department.

There has not been an extensive focus on the process theory since the work has been concentrated to the needs to be satisfied from an increased use of prototypes within the development process. However it might be beneficial to map what needs to be satisfied before deciding on a process to follow.

9. RECOMMENDATIONS

Saab has much to benefit from a more extensive use of different kinds of prototypes. The recommendation will be for Saab to implement the suggested prototyping process. By using the prototype guidance and specification chart in cooperation with the process it will be more user-friendly and easy to understand. The suggested process is developed to cover the range from simple to extensive prototypes and when certain steps are considered not necessary they can be excluded.

Saab should primarily increase the use of the simpler prototypes, also called mock-ups. By increasing the usage of these prototypes positive effects can be achieved that will influence the product development process and the effectiveness can increase.

It will be important to make the project leaders aware of the benefits that can be achieved with a more extensive use of prototypes. Since they are responsible for budgeting it is important that they allocate enough resources to be able to develop the necessary prototypes. It is however also important to make the design engineers realise that prototypes are a powerful tool that can aid the development work. One suggestion can be to include prototypes as a part in the framework of the product development in order to initially force an increased use. One example can be to include criteria regarding prototypes within the gates in the stage-gate process that needs to be fulfilled in order to pass a certain gate. This since a physical model will be easier to understand and evaluate compared to a virtual model.

The suggested classification is to mainly be used by departments developing or working with hardware. Working with and developing software can require a different classification in order to be optimised for the purpose. The classification needs to be spread throughout the organisation and firmly established in order for the new definitions to be used.

SUGGESTIONS FOR FUTURE WORK

The suggested process has been evaluated in a number of workshops. When the process has been implemented into the product development process and somewhat used, there is probably a need for adjustment or optimisation to be fully adapted to how work is conducted at Saab.

There should be a more thorough analysis in the verification of simpler prototypes since Saab has a comprehensive verification throughout the development process. The verification on simpler prototypes is suggested to be more of an approval or easier verification. There also might be a need of establishing guidelines for what is needed for having a full verification on a prototype.

The cost associated with a late change is not easy to quantify. By conducting a deeper analysis of these costs, benefits of using the simpler prototypes is easier to demonstrate when an approximation is known.

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APPENDIX I

INTERNAL INTERVIEWS:

Martin Nyman	Product planning
Jan-Erik Olausson	Project leader
Peter Andersson	Product management
Mikael Palrud	Integrated logistic support
Maria Torvad	System security
Jan Rydén	Senior system engineer
Johan Östberg	Design engineer
Joakim Alhbin	Head of department (Mechanics & Environment)
Pierre Sandgren	Sub-project leader
Thorbjörn Sandgren	System verification
Jenny Andersson	Design engineer
Terje Erstad	Head of section (Mechanical design)
Thomas Bratt	Market department
Hans Wahlström/ Henrik Engström	Mechanical workshop
Stefan Linders	Head of section (Power Airborne, AEW&C & Laser)
Christian Sandberg	Sub-system responsible

EXTERNAL INTERVIEWS:

Johan Hallendorff	Husqvarna group (Team manager Concept & Features)
Peter Hall	Saab AB, Training & Simulation (Head of mechanical workshop)
Mats E Johansson/ Fredrik Kroll	Saab AB, EDS in Jönköping

APPENDIX II

Describe in general your work tasks!

Define a mock-up!

How do you interpret the difference between a mock-up and a prototype?

What type of problems can be solved with an early use of mock-ups (needs)?

What type of information would you like the mock-up to communicate?

How can it be used in the interaction with the customer?

How accurate (close to finalised product) do the mock-up need to be?

Which level to test (component→ system level)?

What would you like to verify with a mock-up?

Do you see a need of a functional mock-up or a design mock-up showing the overall concept?

Are there any particular products where there is a larger need for mock-ups?

What is the most common reason for not using mock-ups?

Is there a possibility of having scaled mock-ups?

How often do you think you can benefit from using a mock-up?

How often do you take potential construction of mock-ups into consideration when making cost estimations?

How is your view on the cost when making mock-ups throughout the project, (do you think that it in the end will be a cost saving)?

How early in the prototype process to be involved?

Do you know if other areas within Saab have a more developed process for making mock-ups?

How can the work conducted within you department be improved by a more extensive use of mock-ups (and prototypes)?

Do you see any problems with the current PD-process when it comes to using mock-ups as a part of this process?

Do you think that more emphasis should be on simpler mock-ups or on more advanced mock-ups (with more functions)?

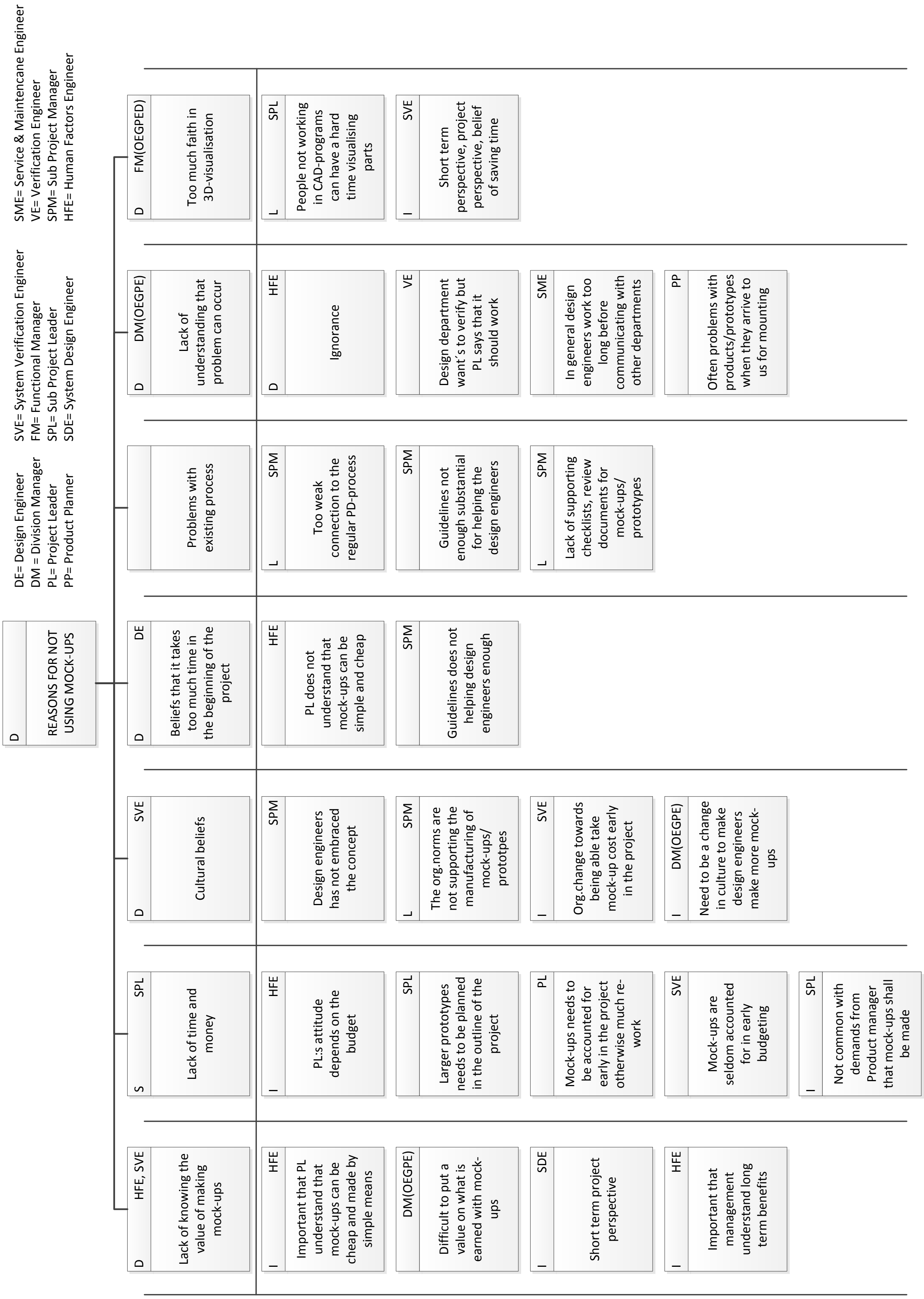
What can be changed in the organisation to encourage the use of building mock-ups?

Do you have any suggestion for the development of the mock-up process?

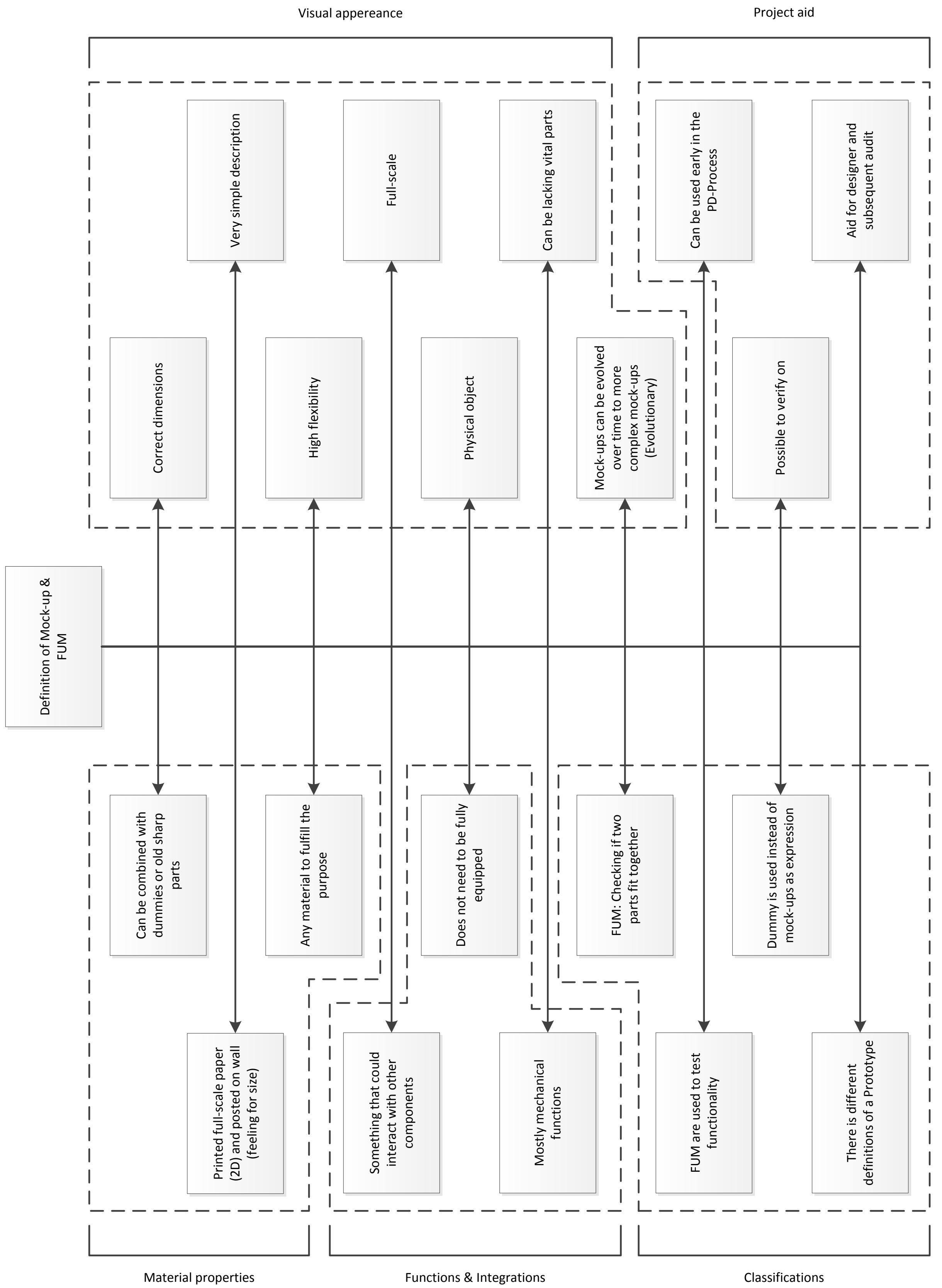
APPENDIX III

	Project framework	Function & Integration	Design & Arrangements	Communication	Human factors
What needs for making a Mock-up?	-Identify problems and minimize risk -Verify in an early stage -Early get a "picture" and show progress -Remove uncertainties, simple and cheap -Contribute to a more effective review	-Test and show simple functions -Practically test ideas and solutions -Test interfaces between components and against external equipments (for verication department)	-Evaluation of serviceability and accesability (space needed) -Create feeling for dimensions -Squeeze and feel -For ergonomics and packability studies	-Visual purpose and create understanding -Early collaboration with designer and system verification -Show future products to customer -Create common picture between dept.	-Understand the product and how to use it -How to handle the product -Testing of human machine interface
How to use the Mock-up?	-For workshops -Early and throughout the PD-process -As a sub-goal -As a milestone -For early evaluations of concept	-For physical verification -Implementation test at customer -In collaboration with sub-contractors	-For concept testing -For hands-on feeling -Space for tools -Test what is possible to reach -Space for exchange of components	-For reviews -At exhibitions and sales meetings -Sharing concepts to customer -In workshops -Evaluate manufacturing methods	-In interaction with the human body
What to verify?	-Project progress -The overall system -All aspects	-That parts work together -Specific functions -How parts fit together	-Access possibilities -Integration and interfaces -Space required for components	-Manufacturability -Fullfillment of customer needs	-Reachability and ergonomics -Interaction with the human body -Aesthetics -For testing usability -Semanthics
Specific products/ components that are more beneficial?	-New products -High risk projects -Large and complex systems -System level -Entire concept	-Connection units -New innovative mechanical solutions	-Rack and components -Packing studies on system level -Products with need of service -Intensively packed products	-Products with many departments involved -Products with high uncertainty -When departments have widely spread interests	-Equipments and interiors -Products in relatively high series -Products with many users -When having inexperienced users
How accurate does the Mock-up need to be?	-Correct meausures but not on detail level -Rough in the beginning and evolves during project	-Enough accuracy for testing intended property -Functions should be made properly -Material properties correct -Less accuracy than real product	-Size and shape correct	-Enough to provide understanding for customers	-Centimeter accuracy -Needs too have maximum or minimum dimensions
Possibility of having scaled Mock-ups?	-When evaluating concepts -Only in very early stages	-When testing different loading cases -When trying interfaces	-If put in it´s correct context/ environment -Not for testing reachability and accesability	-Not only but as a complement -Can be an alternative if full scale is not possible	-Not for mock-ups with Human Machine Interface purpose
Length of manu-facturing a Mock-up?	-Needs to be finalized to a certain level early -Mock-ups on system level can be developed throughout the project	-Approximately 2 days when manufacturing simpler Mock-ups		-Important to analyze when the mock-up does not creating anymore value	
Preferable materials on a Mock-up?	-Cardboard, Foamboard, Wood, Styrofoam, Aluminium	-Properties enough to verify the tested function	-Possibility to use several different materials	-As similar as possible -Needs to look realistic	-Enough robustness to allow interaction with the human body

APPENDIX IV

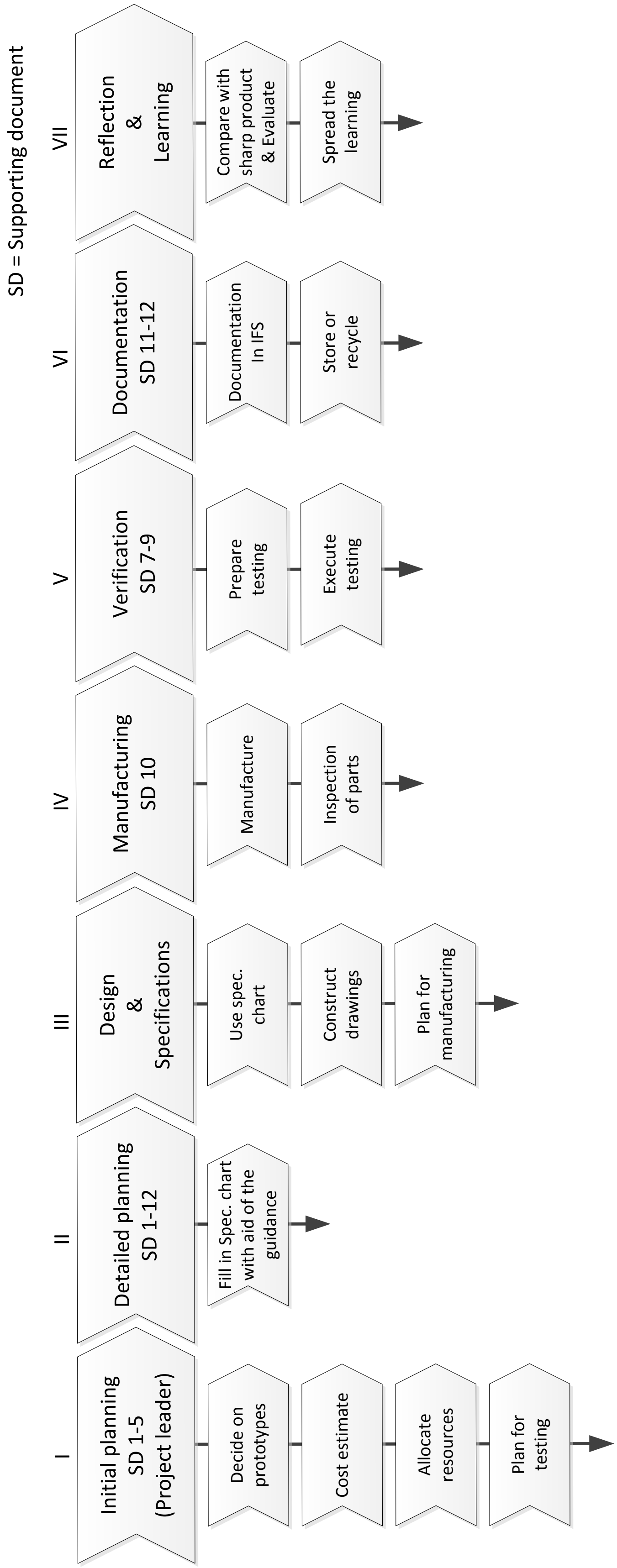

DE= Design Engineer
DM = Division Manager
PL= Project Leader
PP= Product Planner
SVE= System Verification Engineer
FM= Functional Manager
SPL= Sub Project Leader
SDE= System Design Engineer
SME= Service & Maintencane Engineer
VE= Verification Engineer
SPM= Sub Project Manager
HFE= Human Factors Engineer
D REASONS FOR NOT USING MOCK-UPS
D HFE, SVE Lack of knowing the value of making mock-ups
I HFE Important that PL understand that mock-ups can be cheap and made by simple means
DM(OEGPE) Difficult to put a value on what is earned with mock-ups
I SDE Short term project perspective
I HFE Important that management understand long term benefits
S SPL Lack of time and money
I HFE PL:s attitude depends on the budget
SPL Larger prototypes needs to be planned in the outline of the project
PL Mock-ups needs to be accounted for early in the project otherwise much re-work
SVE Mock-ups are seldom accounted for in early budgeting
I SPL Not common with demands from Product manager that mock-ups shall be made
D SVE Cultural beliefs
SPM Design engineers has not embraced the concept
L SPM The org.norms are not supporting the manufacturing of mock-ups/ prototpes
I SVE Org.change towards being able take mock-up cost early in the project
I DM(OEGPE) Need to be a change in culture to make design engineers make more mock-ups
D DE Beliefs that it takes too much time in the beginning of the project
HFE PL does not understand that mock-ups can be simple and cheap
SPM Guidelines does not helping design engineers enough
Problems with existing process
L SPM Too weak connection to the regular PD-process
SPM Guidelines not enough substantial for helping the design engineers
L SPM Lack of supporting checklists, review documents for mock-ups/ prototypes
D DM(OEGPE) Lack of understanding that problem can occur
D HFE Ignorance
VE Design department want´s to verify but PL says that it should work
SME In general design engineers work too long before communicating with other departments
PP Often problems with products/prototypes when they arrive to us for mounting
D FM(OEGPED) Too much faith in 3D-visualisation
L SPL People not working in CAD-programs can have a hard time visualising parts
I SVE Short term perspective, project perspective, belief of saving time

APPENDIX V



Visual appereance
Project aid
Very simple description
Full-scale
Can be lacking vital parts
Can be used early in the PD-Process
Aid for designer and subsequent audit
Correct dimensions
High flexibility
Physical object
Mock-ups can be evolved over time to more complex mock-ups (Evolutionary)
Possible to verify on
Definition of Mock-up & FUM
Can be combined with dummies or old sharp parts
Any material to fulfill the purpose
Does not need to be fully equipped
FUM: Checking if two parts fit together
Dummy is used instead of mock-ups as expression
Printed full-scale paper (2D) and posted on wall (feeling for size)
Something that could interact with other components
Mostly mechanical functions
FUM are used to test functionality
There is different definitions of a Prototype
Material properties
Functions & Integrations
Classifications

Prototyping process



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Classification Defence Secrecy
ÖPPEN/UNCLASSIFIED

Specification chart

Prototype level & Project type (SD 1-2):

CAD-Model/picture

Purpose (SD 3):

Classification & State (SD 4-5):

Testing Properties (SD 6):

Verification (SD 7-9):

Manufacturing and materials (SD 10):

Documentation (SD 11-12):

Time plan:

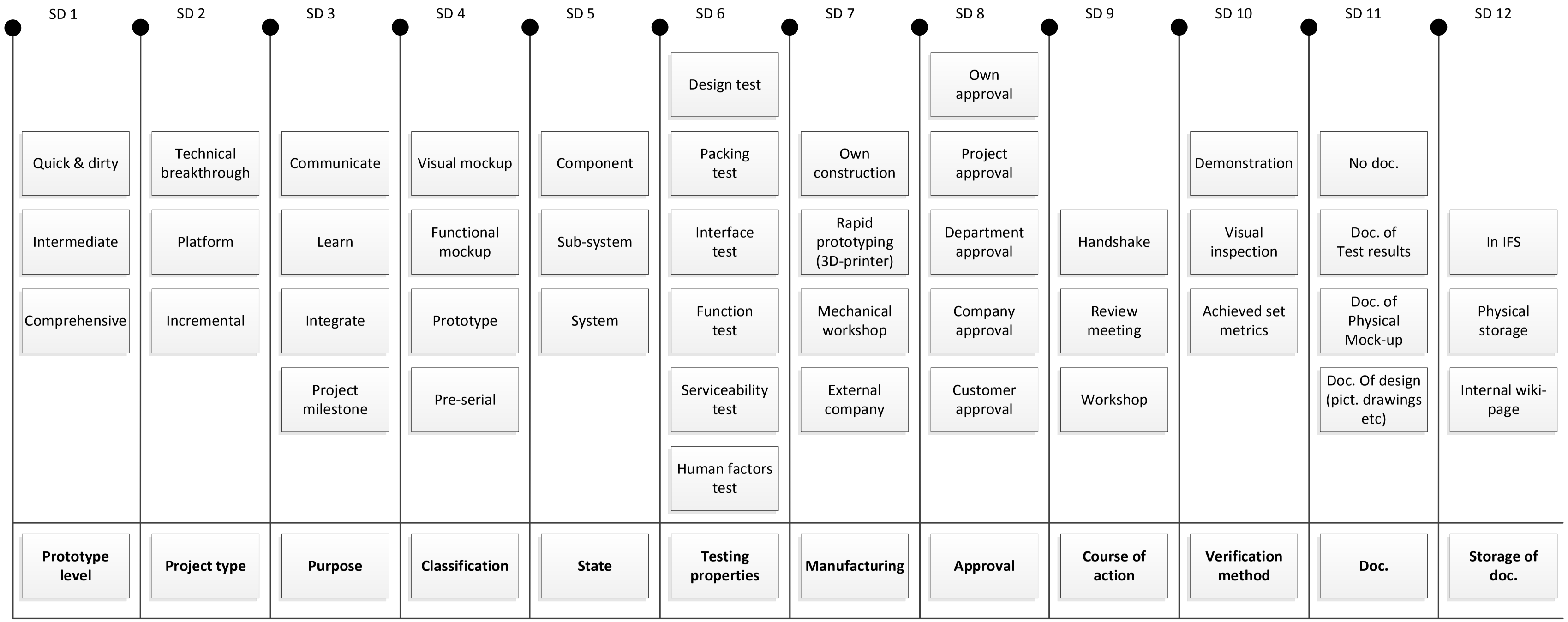
Demands and requirements:

Cost:

Potential risks:

APPENDIX VIII

Prototyping guidance



SD 1

- Level 1 (Quick and dirty)
  - Cheap prototype, guidelines for the cost of this item can be 0-5000kr (but can also depend on the specific type of project)
  - Own verification
  - Own usage
  - Own manufacturing
  - Own authority to take all necessary decisions regarding the prototype

  Process step included: II + III + IV + V + VII

- Level 2 (Intermediate)
  - Relatively cheap, guidelines for the cost of this item can be 5000-25000kr (but can also depend on the specific type of project)
  - Possibility of having represent from Verification & Services
  - Internal usage
  - Manufacturing outsourced internally and/or externally
  - Sub-project leader or Functional manager takes go/no-go decision if developing prototype

  Process step included: II + III + IV + V + VI + VII

- Level 3 (Comprehensive)
  - Comprehensive cost estimation needed (<25000kr, but can also be dependent of project)
  - Verified by verification & Services or other pointed persons
  - Internal and/or external usage
  - Manufacturing outsourced internally and/or externally
  - Project leader or Functional manager or Contract owner takes go/ no-go decision on developing prototype

  Process step included: I + II + III + IV + V + VI + VII

SD 2

- Technical breakthrough project
  A project which is aiming at developing a new kind of technology. The focus is to achieve superior technical performance. Creates know-how and know-why knowledge.
  Prototypes within this type of project should be an aid for the engineer, providing rapid feedback about feasibility, limitations and learning is an important purpose of the prototyping.

- Platform, next generation project
  This type of project is to developing the next generation products. Focus is on achieving a superior system solution. Product architecture and the behaviour of the product as a whole system are of importance.
  Prototypes should support the cross-functional communication, and should have a system focus. Important purpose of the prototypes is integration and communication.

- Incremental project
  Within this type of project the new product is based on an established platform which lead to that the basic architecture is unchanged. The product is seen as a modification to the prior product with for example certain updates. The prototyping focus should be on early involvement and input from manufacturing.

SD 3

Important aspects to consider regarding the different purposes of using prototypes

- Communicate:
    - Think about what the prototype/mock-up should communicate and who is to be communicated with e.g. customers, management or other departments.
    - It is important to consider what type of feedback that is requested and how the feedback is to be documented so that the information is preserved.
    - Consider how to design the prototype/mock-up to increase the possibility to receive the intended feedback, e.g. material or level of details.
- Learn:
    - Learning is an important part in the usage of prototypes, questions such as "is this a possible solution" and "will it work" can be answered.
    - If someone else (people from other departments) is going to teach something think about the communication.
    - Consider how to document what has been learned and how this can be transferred to other co-workers, later stages in the project or other projects.
- Integrate:
    - Integration can be testing the interfaces between physical components or sub-system within the system and to detect interference between them.
    - Integration forces different parts of the project to coordinate and assemble the different parts developed
    - In addition to testing physical interfaces integration can combine different perspectives from different departments.
- Project milestone:
  The mock-up or prototype can be a part within a stage-gate and intended to be used to verify certain aspects within the product or that the project has reached a certain stage. Every people from the project are attending and the mock-up shows the progress within the project.

SD 4

- Visual mock-up: This type of mock show the outer appearance, design, shape and size. Important that the mock-up has accurate size, shape and outer geometry. If the mock-up is to be used for communication with other departments outer appearance will be more important. If it will be used to communicate with external customers the appearance will be of high importance and surface finish needs to be of high quality.

- Functional mock-up: Is used for trying different functions or try different interfaces between parts or components. These types of mock-ups have lower demands on the outer appearance and correct proportions. Though important to consider needed accuracy and demands on the details needed to test the interface or the function in order for the test to provide useful results.

- Prototype: A combination of a visual and functional mock-up. Is used to verify the design and functionality when both are set. More documentation is required and the intention is to evaluate the design in combination with the functionality of the future product. The functionality of different sub-system is to be tested in relation to each other. Compared to the actual product there can be differences such as regular steel instead of stainless steel or other small deviations compared to the product. Though important that all physical phenomena is tested and that the tests are credible compared to the actual product.

- Pre-serial: Very similar to the actual product. The pre-serial is subject for final verification before releasing and approval of the actual product. Should be built in close cooperation with the department responsible for the verification in order to ensure an item that fulfils the necessary requirements needed for verification.

SD 5

- Component – Defined as a component that is used within a sub-system and could be for example a box containing several electric components or single components. Consider the components interaction with other surrounding components.

- Sub-system – Part of an entire system and is typically divided in different functions for the system, could be for example the hydraulic system. Consider the sub-systems interaction with other included sub-systems.

- System – Defined as the complete product and includes every function that contributes to the overall performance of the product.

SD 6

- Design test – Connected to the conceptual design and shows the outer shape and most important properties.
  The purpose can be to get an initial feeling of the visual appearance.
  Materials can be simpler, for ex cardboard or foam board etc.
  Not too many/or any details or functions needs to be integrated.

- Packing test – Connected to the conceptual design. Medium-high importance on accuracy on details and measurements. Low demands on material properties.
  Think about departments which can have interest in the packability → get feedback.

- Interface test – Important to have enough accuracy of the mock-up in comparison to the surrounding components. Not always necessary to have a full-scale mock-up to be able to test the interface.
  Which are the interested departments?

- Function test – Important to have sufficient material properties that could correspond to the material that would be used in the sharp product. Not important to put effort on design and aesthetics.
  Simpler mechanical function to test, e.g. "gejdrar"

- Serviceability test – Highly important to have correct shapes and dimensions. The mock-up needs to be in full-scale since it has to collaborate with the human body. Not important to have a high accuracy within the manufacturing process.

  For example test the reachability within the system when components are to be exchanged or to connect external equipment for conducting service or maintenance on the product.

- Human factors test - Highly important to have correct shapes and dimensions. The mock-up needs to be in full-scale since it has to collaborate with the human body. Not important to have a high accuracy within the manufacturing process. Should be easy to rebuild the mock-up in order to test several different settings. Establish contact with Human Factors (HF). The mock-up should be developed in collaboration with Human factors. Important features, characteristics and useful information are provided by Human factors. Possibility of using Human factors workshop in the RUAG house.

SD 7

- Own verification – Aims for only having a very simple verification where it is possible to make an own verification and where there are no demands on the verification method.

- Project verification – The project group or project manager will make the verification and can be made by having a review on the documentation of the included or conducted tests or by visual confirmation.
  Can be a formal process for e.g. reviews or an informal verification by handshake.

- Department verification – The prototype goes through several verifications and has an ongoing documentation of approvals and opinions from review meetings. Formal process that is built upon metrics.

- Company verification – Same as the department verification but extended with a top management commitment. Concept level or higher system level to be verified.

- Customer verification – Informal or Formal process when the verification is made verbally and when the fulfilment of requirements is measured by interpreting the customer reactions and feedback in an informal or formal interview. Could be beneficial of making some kind of written documentation.

Manufacturing techniques for Prototypes

Metals	Styrofoam	Plastic	Paper	Cardboard	Wood	Clay	Aluminium profiles	Materials
Milling Turning Cutting	Milling Cutting	Milling Turning Cutting Rapid prototyping (3D-printing) Freeform technique	Cutting Freeform technique	Cutting	Milling Turning Cutting	Freeform technique	Cutting	Shaping
Brazing Welding Mechanical Tape Nuts/ Bolts Adhesives	Mechanical Tape Nuts/ Bolts Adhesives	Tape Adhesives Mechanical Nuts/ Bolts	Tape Adhesives	Tape Adhesives Mechanical Nuts/ Bolts	Tape Adhesives Mechanical Nuts/ Bolts		Tape Nuts/ Bolts	Joining

SD 8

- Handshake - Used when there is no requirements of a having a formal process and can primarily be used in order to getting an approval to continue with for example the design or the concept.

- Review meeting - Connected to the project and is a formal procedure where the responsible is presenting the subject to the review group. Often some kind of supporting documents is used (checklists). Either the subject is approved or there is a need of some modifications before next review.

- Workshop - Used for gathering important people around the mock-up in order to get a common picture of the subject and to get feedback and approvals for designs. Could be a very useful way to conduct an effective development that reduces the risk of not meeting customer requirements.

SD 9

- Demonstration – Demonstration is used to verify the requirement by pass/fail criteria at the time of the test case execution.

- Visual inspection – Used when it is enough to ensure the feature by only having a visual control and when it is obvious if the prototype and its specifications meets the requirements or not. Visual inspection consists of examination without the use of precision measurement equipment.

- Achieved set metrics – Ensuring the subject by comparing metrics from requirements and measured outputs from the prototype. Used when having more complex subjects and when there is a need of having verification by analysing the system or subject in more detail.

SD 10

- Own construction – Used for simple mock-ups when the time is limited and there is a small need of accuracy and specific materials. Can be a good option if there is a limited basis of drawings and other specifications. **Very Cheap**

  The own construction can preferably be made in the vehicle hall inside the area that relates to Verification & Services. Easier mechanical tools are available.

- Rapid prototyping (3D-printer) – An automated process that has a relatively high accuracy and is a fast method to use if there is a complete CAD-model made beforehand. Limitations in size and is best used if there is complex geometry on the component. Only possible to make plastic models. Post-processing can be required. **Relatively cheap**.

  The Rapid prototyping machine that can be used inside the company is located in Järfälla.

- Mechanical workshop –Is located in the basement at Saab EDS Kallebäck. No special requirements of drawings and specifications and have the possibility of manufacturing custom-made mock-ups. Good accuracy and has the possibility of manufacturing in several materials but is specialised in aluminium. Relatively low lead time and has a good collaboration with external companies if there is special requirements that cannot be fulfilled or the mechanical workshop is overloaded.

  Available equipment is three CNC-machines, welding equipment, bending machines, chop saw, measurement machine, lathe machine (turning), pillar drill, ventilated cabinet and some other easier manual tools. One of the CNC machines is equipped with a 5-axis rotation.

  The largest CNC machine can handle parts of approximately 600*300*300mm

  Lead-time for manufacturing is approximately 1-1,5 weeks without surface post treatment (+ 1 week with post treatment).

No specific demands on drawings, could be anything from hand-made drawings to a complete set of computer made drawings from the CAD-program. If there is a demand on having the data stored the mechanical workshop has a demand that the part/parts have a specific part number and audit mode.

There are no requirements of a specific procedure to follow when order but normally are documents and specifications sent by E-mail.

- External company – Opportunity of choosing from several suppliers and the manufacturing method. More extensive logistics compared to manufacturing in-house. Good possibility of having complete custom-made products. **Relatively expansive**

SD 11

- No documentation – Used when there is no documentation required and when there is only a verification for the own purpose. Should only be used when it is obvious that there is no need of having any documentation.

- Documentation of test results – Should be used when there is a possibility of using the test results in later stages or in other similar projects. Could be useful to be able to show test results for customers or potential customers. Decide if there is a possibility that other departments can take advantage of test results in later stages.

- Documentation of physical mock-up – Could be used especially when having small scaled-models that can be stored in lockers where other people within the company can gain feedback or inspiration for own design work. Depending on scope of the mock-up some full-scale models should also be considered to store in some way. If the mock-up should be stored, it needs to have an identification number that could be used to track supporting documents for the mock-up in IFS.

- Documentation of design (drawings etc.) – Since most of the design for the mock-up is made in digital form it is recommended to document the design in order to have the possibility to gain advantage in later stages from the documentation.

SD 12

- In IFS – The IFS is used as a PLM-system where almost every digital documents for the company are stored. This gives the possibility of having good searching capabilities and where it also is possible to see the status of the document. Every document has a specific number that can be traceable and show the type of document.

- Physical storage – Depending on the size of the mock-up there is several storage possibilities such as lockers for small mock-ups and larger storages such as the storage in Landvetter.