Modularization of Saab EDS ground products

Master of Science Thesis

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Abstract

The project sponsor Saab Electronic Defence Systems (EDS) faces a new situation. External sponsors no longer finance research and product development. This has forced the company to secure a higher payoff on developed products and allocate development resources with a longer perspective. The market is requiring of the shelf products, which easily can be adapted to a low cost and delivered at the right time. Due to the changed conditions Saab EDS has recently launched a Base Line Product programme, intended to serve as a future platform.

The overall purpose of this master thesis is firstly to establish a method suitable for dividing the Base Line Products into defined modules on different system levels. Secondly, to illuminate how organizational aspects are correlated to modular product architecture and suggest organizational changes. Thirdly, develop a model calculating the cost of changing interfaces as a result of customer adaptations.

This is achieved by a literature review combined with studying the company situation. The company situation is analysed by investigating internal documentation, making observations, and performing interviews. The intent is to compare the literature with the current company situation and implement a modularization strategy. The strategy is a combination of different methods and tools derived from literature. The method Modular Function Deployment is used to define modules in the current configuration of the two systems Arthur and Giraffe AMB. Interfaces between defined modules in the systems should be standardized. A concept for categorizing interfaces into A-, B-, and C-class depending on their importance is presented and applied in the company context.

Combined with a modular strategy the aspects of organization are discussed and a proposal of organizational changes is introduced. The master thesis introduces Interface Managers, Module Managers, and cross-functional module teams into the current organization with a one-to-one mapping with the systems.

Benefits and economical aspects of modularization are discussed on a theoretical basis and applied to the company situation. A framework for estimations of cost, based on cost driven activates adopted from Activity Based Costing is presented to demonstrate how changes in interfaces widespread in both the products and the organization. The intention is to be able to make appropriate decisions when faced with customer demands that interrupt the standardized interfaces that cannot be foreseen in advance.

As a general conclusion it is proposed that Saab EDS should continue working with the Base Line Product programme. However the company should allocate recourses to define modules included in the baseline products and standard customer options. It is essential to standardize interfaces to make the development process decoupled and more insensitive to customer demands. Saab EDS should also deposit recourses to an organizational change by complementing the organization with managerial responsibility for the modules and the interfaces.

Key words: Modularity, module, modularization, product architecture, interface, modular function deployment, modular organization, module drivers, and organization.

Acknowledgements

This master thesis was written to clarify the mechanisms behind modularity and describe how a modular strategy could be implemented at Saab EDS. It was conducted at the Division of Operations Management at Chalmers University of Technology.

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Johan Granström & Victor Hagman

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Abbreviation list

ABC	-	Activity Based Costing
AMB	-	Agile Multi-Beam
ARTHUR	-	Artillery Hunting Radar
BU	-	Battery Unit
CDU	-	Control and Display Unit
CS	-	Cooling System
DAU	-	Dry Air Unit
DSM	-	Design Structure Matrix
DU	-	Display Unit
EDS	-	Electronic Defence System
FSHM	-	Function Structure Heuristic Method
HMI	-	Human-Machine Interface
ILS	-	Integrated Logistic Support
LPU	-	Low Power Unit
MDF	-	Modular Function Deployment
MIM	-	Modular Indication Matrix
MPM	-	Modelling the Product Modularity
PCP	-	Power Control Unit
PDU	-	Power Distribution Unit
PDM	-	Product Data Management
PIP	-	Power Inlet Panel
PRI	-	Product Revision Information
PP	-	Power Plant
PS	-	Power System
PU	-	Power Unit
RAM	-	Rockets, Artillery & Mortars
SDU	-	Signal & Data processing Unit
TRU	-	Transceiver Receiver Unit
QFD	-	Quality Function Deployment

1 Introduction

This chapter presents the master thesis *Modularization of Saab EDS ground products*. It includes a background of the company and the company situation, purpose, limitations and questions at issues, as well as a general description of the report structure.

> *We can't solve problems by using the same kind of thinking we used when we created them. – Albert Einstein*

The project sponsor Saab Electronic Defence systems (EDS) faces a new situation. External sponsors no longer finance research and product development. This has forced the company to secure a higher payoff on developed products and allocate development resources with a longer perspective. The market is requiring off-the-shelf product, which easily can be adapted to a low cost and delivered at the right time. This causes problems requiring new working methods.

1.1 Background

The project sponsor Electronic Defence Systems is a business segment within the Saab Group AB. The Saab Group is one of the world leading suppliers of surveillance-, avionic-, and defence systems developed to detect, locate, and protect against threats. Saab EDS develops and manufactures radar systems for a variety of application areas. The systems Artillery Hunting Radar (Arthur) and Giraffe Agile Multi-Beam (AMB), Figure 1, are developed for reconnaissance and artillery localization. Both systems are ground based, used to scope land. They provide the commander with the capability to quickly locate firing artillery weapons and estimate the impact points in advance. Giraffe AMB exceeds the scope to primarily monitor airspace and in addition to artillery, also warn against incoming rockets and mortar projectiles (RAM).

Figure 1 - Arthur (left) and Giraffe AMB (right).

Arthur and Giraffe AMB are developed and manufactured in short series with specific customer requirements. Development activities are first and foremost located in the engineering to order process. Development cost and lead-time are determined by the ability to re-use components and sub-systems already developed. The re-use capability is essential in order to offer the market right products at the right time and to the right cost. Variety is created early in the development process. The current situation demands a lot of re-work on the systems, to adapt towards customer requirements.

Modular product architectures by forming building blocks with clearly defined interfaces at different system levels give opportunities for continuous development of the systems. This should be done without regards to specific customer requirements, thereby pushing the creation of variety to the latter parts of the development process. Modular architecture is also beneficial since it gives opportunities for adapting parts of the product to customer requirement without affecting the product as a whole. Since two separate systems are included in the thesis with similar application, reusability and the possibility of shared modules in the systems would dramatically decrease the administration of components. Saab EDS has a part library exceeding 100 000 components, which all allocate costs including inter alia maintenance and development. A reduction of the number of components and possibly use the same components between the two systems would imply opportunities to benefit from scale effects. The master thesis is considered as a subset of the activities at Saab EDS correlated to a re-design into modular product architecture with existing configuration as basis.

1.2 Purpose

The overall purpose of this master thesis is firstly to establish a method suitable for dividing the Base Line Products into defined modules on different system levels. Secondly, illuminate how organizational aspects are correlated to modular product architecture and suggest organizational changes. Thirdly, develop a model calculating the cost of changing interfaces as a result of customer adaptations.

1.3 Limitations

The general analysis of this master thesis is performed at a holistic level. The scope of the thesis will be narrowed down to a manageable level using a funnel approach by identifying areas on high system level that have strong reasons for modularity. An in-depth analysis will proceed only of a sub-set of the identified areas.

The change from an integrated- to modular product architecture is not done on the entire systems Arthur and Giraffe AMB. Areas within the systems considered most suitable for modularization are chosen and the rest is left unchanged. The reason is modularization of the entire systems would have been extensively and exceeded the timeframe of the thesis. The organizational analysis suggests a revised organizational structure. The organizational structure presented is based on theoretical analysis and not validated by interviews at Saab EDS.

1.3.1 Secrecy

Company classified material are removed from this thesis. Figures are blurred, part-numbers are hidden or removed, values in tables are removed, and financial values are presented in non-realistic values. Saab EDS department abbreviations used in the report cannot be located in the organizational structures presented. The secrecy editing has been performed carefully to not change the overall meaning of the affected parts.

1.4 Questions at issue

The following set of question is based on the purpose of the thesis. The questions translate the purpose into hands-on questions answered by the master thesis.

- How can modules be defined in the current configuration of the two systems and how are modules selected for further decomposition?
- Can the two systems share modules and how can scale effects be accounted for?
- What organizational changes need to be considered at Saab EDS? Is it possible to combine modular product architecture with a coupled organizational structure?
- Who will be responsible for the modules within the function and how are changes in modules handled in the organization?
- How can a modular architecture reduce cost and lead-time in the engineering to order process?
- How should substantial customer adaptations requiring changes in interfaces be handled?

1.5 Report structure

Chapter 1 presents an introduction to the master thesis. It includes a background of the company and the company situation, purpose, limitations and questions at issues, as well as a general description of the report structure.

Chapter 2 explains the current organization and the Base Line Product. Discussing difference in the past and the present situation, which has resulted in strategical challenges for Saab EDS.

Chapter 3 explains the master thesis approach, workflow, methods incorporated, and a discussion regarding validity and reliability of the sources.

Chapter 4 provides the theoretical framework of the master thesis. It is built on three cornerstones, product modularization, organization, and cost and lead-time aspects.

Chapter 5 presents the result of the analysis conducted. It presents defined modules and classified interfaces on a sub-set of the systems. Organizational implication is considered and changes proposed. Further a framework for estimating costs due to customer adaptations and changes in interfaces is developed.

Chapter 6 discusses the result and the analysis conducted from the authors' perspective.

Chapter 7 presents the conclusions. The conclusions are the outcome of the result and linked to the overall purpose of the master thesis.

Chapter 8 provides recommendations for implementing a modular strategy. An A3 is presented as a summary, visualizing the steps completed in the report.

2 Company description

The company has recently introduced a Base Line Product programme. This chapter explains the current organization and the Base Line Product. Discussing difference in the past and the present situation, which has resulted in strategical challenges for Saab EDS.

2.1 Organization

Saab EDS Operations Gothenburg (OEG) is currently organized according to a traditional line organization (Rubenowitz, 2004), see Figure 2. The functions have technical authority within each area of expertise but are financially dependent on customer projects to allocate resources. The projects distribute resources according to activities needed. The dependencies of the projects create short perspectives on development activities leading to a reactive strategy. The reactive strategy results in integrated systems and inferior product standards and processes. It also periodically puts large pressure on the engineers, which forces them to work extensive over-time.

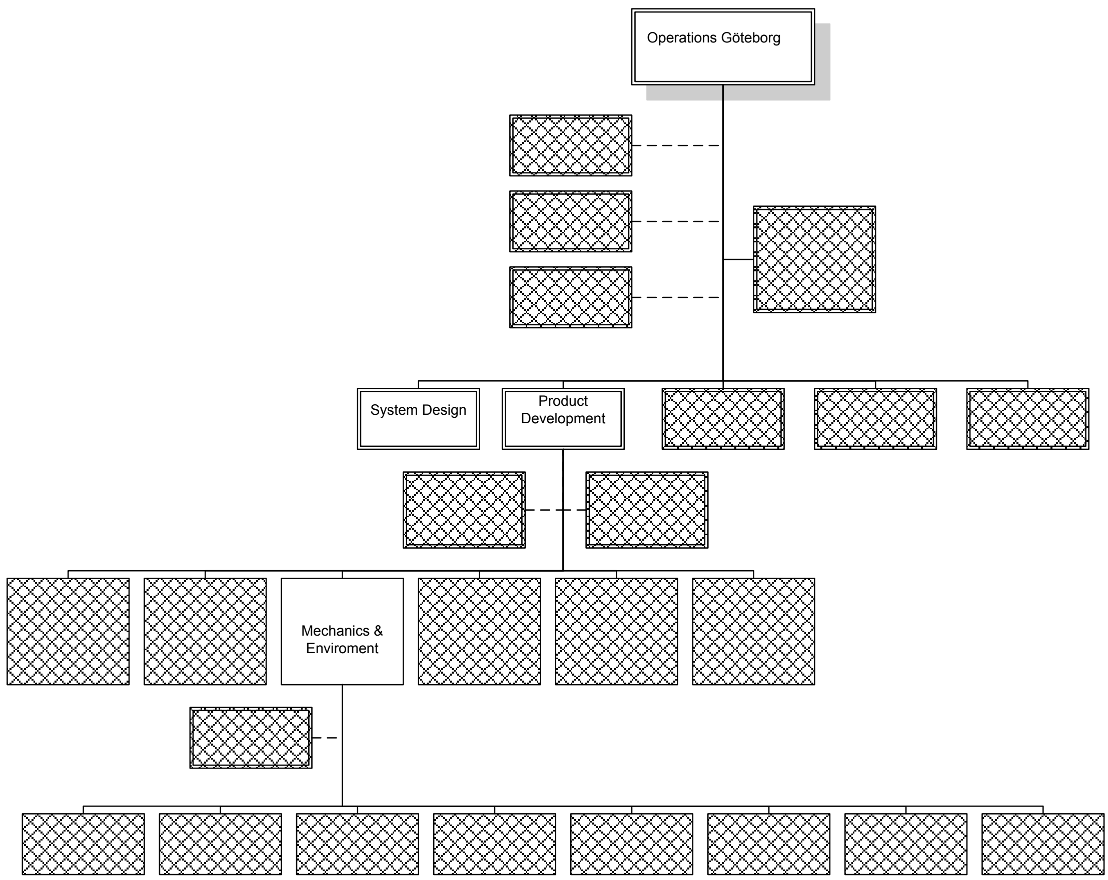

Figure 2 - Saab EDS organization chart

Previous Saab EDS customers have required custom built systems and have been willing to finance the development. A major customer has been the Swedish Defence Material Administration (FMV). But the market environment is now changed, as customers want to buy product off-the-shelf and not finance development activities to the same extent. The projects are still order specific creating problems for Saab EDS to handle variance in a smart and effective way. The previous development has resulted in integrated systems and dependencies between development activities. The development activities have to a great extent been financed by projects with origin in customer orders. A sponsor (Project Manager) receives information from the customer including a technical specification and a product definition.

The line organization at Saab EDS has several hierarchical levels. The combination of having integrated product architecture and time consuming processes for strategic decision-making enhances development lead-times. The responsibility for parts and sub-systems on low system level are in many cases unclear. Integrated technical solutions and re-engineering of parts are therefore often selected, in order to keep the work within the allocated time. According to engineers at Saab EDS, communication between different projects and functionally coupled systems consumes many hours in their daily work.

The correlation between projects and the line function varies at Saab EDS. According to engineers at different departments the projects are powerful as the product is close to the customer. This is especially the case for the department OEGPE. Since OEGPE is developing the systems close to the customers their work is strongly influenced by the customers' requirements. They perceive pressure to deliver technical solutions within the timeframe of the project fulfilling the demands of the customer. Other departments are stronger, compared to the line functions. OEGPU and OEGPP are examples of functions delivering arranged services to the projects and are thus less dependent on the financing of the customer projects.

Each function within the company has a manager and each area of technical expertise within the function has a manager. The Subproject Managers at Saab EDS are organizationally placed outside the technical functions. The Subproject Managers are responsible for the allocation of engineering hours but have no technical authority. The engineers at Saab EDS thus have both a technical manager in the line function and a Subproject Manager responsible for their time. When situations arise and systems in one project affect systems in another the communication patterns are complex and time consuming.

2.2 Products

The systems Arthur and Giraffe AMB are heavily influenced by Saab EDS relationship to the customers. With timely bidding processes on a competitive market the Saab EDS portfolio of products are customer adapted. Customer projects, which previously have been financing development activities, have resulted in big development steps, Figure 3. By having strong projects and weak line functions the product architecture must be adapted to the projects. It is costly for the company to open up the product structure for every customer. For each project the production needs to individually customize their planning and setup resulting in high costs. The customer adaptations add to the integrated product architecture. The integrated architecture results in difficulties creating standards between sub-systems within the product and optimizing the system as a whole.

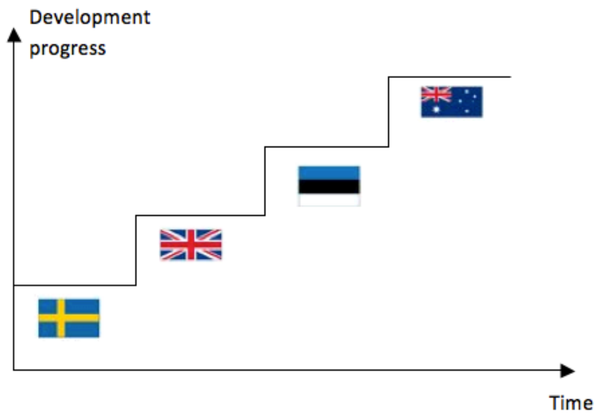

Figure 3 - Development progress for Giraffe AMB has previously been located in customer projects.

The integrated product architecture demands extensive activities keeping track of versions of components and products. All minor changes must be documented in the Product Data Management (PDM) system IFS. Within IFS all documents are stored as products no matter if it is a project, product or component.

Product structures studied demonstrate that the two systems are hierarchical constructed with decomposed functional areas or base modules that form the system. The product structure according to the product definition includes 3-4 levels that constitute the systems, but are not structured around a similar framework.

To better map with the customer demands of short delivery time and off-the-shelf pricing the company has developed a new Base Line Product for the systems Arthur and Giraffe AMB. The Base Line Products are the last developed versions of Arthur and Giraffe AMB, called Mod C. The Mod C systems are theoretically build of base-modules and a number of standard options, Figure 4. Product management develops and are responsible for the Base Line Products, compared to projects traditionally run by project management. The company has thus organizationally shifted development focus from projects to development within the line functions. The challenge for the Base Line Product structure is how to translate a theoretical framework into engineering practice. The challenges are to implement the same new procedures for both Arthur and Giraffe AMB, and to manage the base-modules over time.

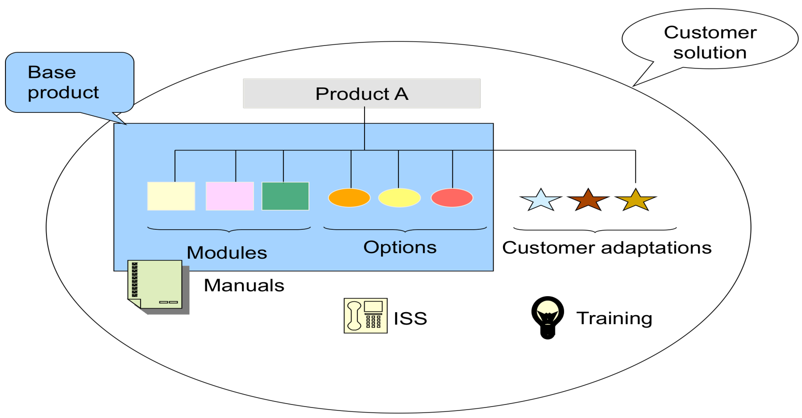

Figure 4 - Base Line Product definition by Saab EDS (Falk, 2012).

3 Methodology

This chapter explains the master thesis approach, workflow, methods incorporated, and a discussion regarding validity and reliability of the sources.

3.1 Approach

The activities for this master thesis are schematically planned using a Stage-Gate strategy for development (Cooper, 1990). Stages with corresponding gates were used to structure the activities. At the gates work was approved and support given in order to secure that the thesis was headed in the right direction.

The master thesis began with an information gathering including product and company understanding, data collection and literature review. In order to create a modularization strategy at Saab EDS build on the most relevant literature many different modularization methods were analysed. The literature methods most suitable for Saab EDS was selected and combined to form a company specific modularization method.

The thesis main focus is on three aspects of modularization; the product, the organization and costs aspects connected to modularization and customer adaptations. Documentation continued throughout the entire project. Complementary information gathering were conducted to support the on-going process when considered necessary. The workflow for the master thesis is schematically described in Figure 5.

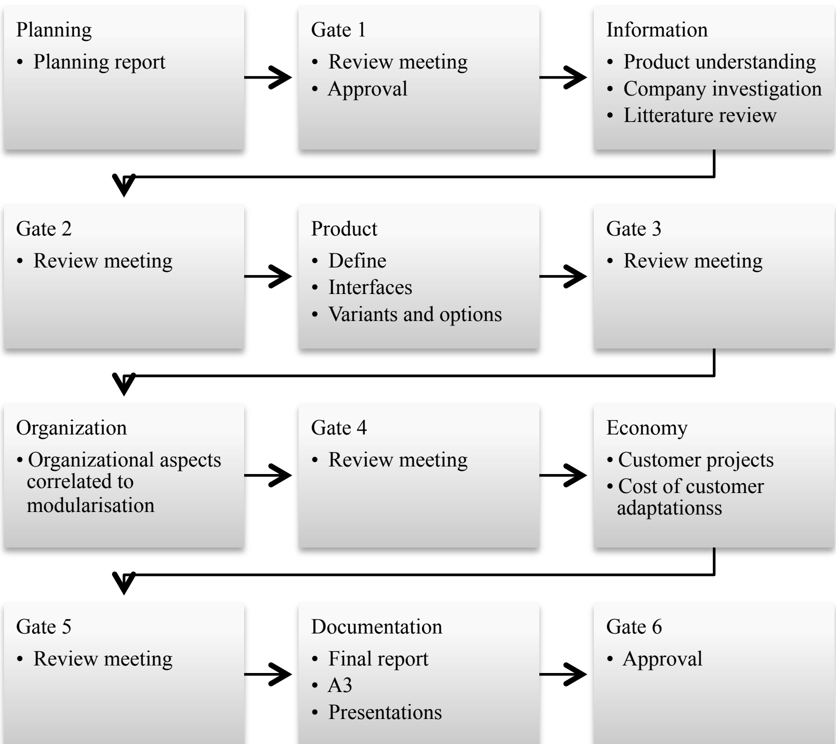

Figure 5 - Master thesis workflow chart.

3.2 Sources

A wide variety of sources were used in the master thesis, both external from literature, as well as internal sources within Saab EDS. According to Yin (2003) using a wide variety of sources are complementary, he argues that no single source is solely advantageous hence it is beneficial to use a set of sources instead of depending solely on a single source. The different sources used are presented in this section.

3.2.1 Interviews

To get an adequate background of the current situation at Saab EDS, a set of ten semi-structured in-depth interviews with open-ended questions were conducted, Appendix 1. According to Carlsson (1997) semi-structured interviews provide reliable information. Semi-structured interviews were chosen because qualitative information was preferred opposed to quantitative. Semi-structured interviews also allowed for probing. Interviews are an important source when understanding company specific information (Yin, 2003). Interviews as a data collection method was preferred since it is relatively easy to pinpoint the information wanted. Yin (2003) argues that interviews can be biased but if performed correctly is the most important source of information. The interview lasted for 30-60 minutes and two interviewers participated. The intention was to create a discussion, to get an insight and to extract problem areas correlated to both the product and the company. To extract possible reasons for modularity in the entire life cycle of both the product and the organization was examined.

Various departments and employees on different positions in the organization were interviewed. The positions of the people included were; product development engineers, system engineers, product managers, purchasers, production engineers, quality and aftermarket engineers. Further the interviews helped to illuminate problems in the company's current situation and hence clarify the purpose for this master thesis. Information gathered from the interviews was also used in the product modularization as help in the assessment to determine properties of various sub-systems. The information derived assisted to make the product modularization as reliable as possible. The opportunity for follow-up questions via email was also used to receive additional information when needed.

3.2.2 Group discussions

Saab EDS employees from various departments experienced in cost estimations participated in a group discussion. Participants of the group assessment for the scenario are presented in Appendix 1. The discussion was performed in the same way as the company usually perform cost estimation meetings. A scenario describing changes of a product resulting in change activities was presented to the group. Each participant presented the data correlated to his/hers area of expertise according to the changes needed of the product. The information used a funnel approach beginning with the obvious costs associated with the change and then breaking it down to manageable cost packages. Carlsson (1997) argues that the funnel approach is fundamental for the unstructured group discussion. The information about gathered was used to assess quantitative sums in the analysis.

A second group discussion took place as Saab EDS presented the Mod C Base Line Product programme, Appendix 1. A presentation regarding general properties and mechanism behind modularity were performed. The meeting lead to thorough discussion and information about Saab EDS currently situation and endeavour against modularization.

3.2.3 Literature

A large amount of literature on the subject of modularization including relevant articles, journals, thesis work, books, and presentations has been studied in the master thesis. The literature search has to a great extent been allocated to material discussing modularization of the systems, organizational aspects of modularization and cost effects correlated to a modular strategy. Literature was primarily retrieved using Chalmers library and the Chalmers online catalogue CHANS.

3.2.4 Internal documentation

Internal Saab EDS documentation present in the internal PDM system IFS was studied including technical descriptions, product definitions and structures, wiring diagrams, system layouts, and product drawings. Internal documentation is useful documentation that can be used in the data collection, however documentation should not be equivalent to literal recording of past events (Yin, 2003). The intent was to derive system understanding but also to further derive information regarding system properties to enable a credible assessment. Internal cost assessments and quotations where studied to derive information regarding cost connected to customer adaptations.

Further organizational structures were investigated to derive information about the current organizational situation and why and how customer projects are considered so powerful. Information regarding current processes, working procedures, and operation systems were derived for Saab Groups internal webpage Saab NET and was used as a complement to investigate how the various kinds (customer and internal development) of projects are conducted and what activities are present in Saab EDS current processes.

3.2.5 Observations

Since Saab EDS has production and systems assembly in-house numerous visits both guided and individual in the workshop and installation hall were conducted. These visits were especially important in the beginning of the master thesis to get product knowledge and feeling regarding the hardware. The observations were unstructured and can therefore according to Carlsson (1997) not be used as trustworthy information.

3.2.6 Benchmarking

Modularization is a well-known strategy, which are used widely in industry. Other companies' work with modularization was studied to get inspiration to the coming suggestion for Saab EDS. Companies targeted for benchmarking encompasses Scania AB, Volvo Cars AB, Volvo Trucks AB, and BAE Systems Hägglunds and information were primarily derived through lectures and printed information available publicly.

3.3 Validity and reliability

The master thesis is built around a literature review and data collection with input from multiple sources including interviews, group discussions, documentation, and observations. To assure validity of this master thesis information was collected from different sources and from respondents with different organizational positions. When using documentation in the data collection it is important to question the validity of the data (Carlsson, 1997). Studied documentation was relevant and up to date and considered valid.

The authors of this thesis have conducted all interviews, during which notes have been taken and subsequently documented. Yin (2003) argues that interviews can be biased. However to gather information regarding the company situation and data for the following analysis interviews were considered suitable. Saab EDS employees were exclusively interviewed and are considered to be reliable.

4 Literature review

The theoretical framework of the thesis is built around three cornerstones, product modularization, organization, and cost and lead-time aspects. To connect the cornerstones, literature was analyses in order to find a suitable method to build the thesis from. The chosen method was complemented with a wide variety of sources in order to adapt the method to the situation at Saab EDS. Literature also complemented the processes established in Saab EDS and put them in a wider context. A wide variety of theoretical sources were analyzed from different perspectives in order to understand all factors influencing modularization at Saab EDS. It was possible to make connection to the Base Line Product programme introduced by the company.

The base line products are considered as a future platform for the systems Arthur and Giraffe AMB. The challenge is to combine the Base Line Products with a modularization strategy with well-defined interfaces. According to Meyer and Lehnerd (1997) a platform is defined as:

> *A product platform is a set of sub-systems and interfaces that form a common structure from which a stream of derivate products can be efficiently developed and produced.*

Product platforms are frequently mentioned together with a modularization strategy as a set of sub-system and interfaces developed as a common structure, from which derivate products can be derived (Blackenfelt, 2001). According to Baldwin and Clark (1997) modularization is defined as:

> *Building a complex product or process from smaller sub-systems that can be designed independently yet function together as a whole.*

The implementation of the Base Line Products has several attachment points in common with modular product architecture. By working with well-defined product interfaces the delivery time can potentially be significantly shortened, but still enable variation to the customer.

4.1 Products

There are an abundance of different methods for product modularization described in literature. The methods studied was limited to the four product development methods; Design Structure Matrix (DSM) (Ulrich & Eppinger, 2008), Function Structure Heuristic Method (FSHM) (Huang & Kusiak, 1998), Modular Function Deployment (MFD) (Erixon, von Yxkull, & Arnström, 1996) and Modelling the Product Modularity (MPM) (Zamirowski & Otto, 1999). These structured methods for modularization are defined as distinct, hands-on methods clearly described in literature and were therefore chosen for investigation. The methods can although be of very different nature regarding complexity, clarity, and magnitude.

As a first distinction it can be recognized that the methods DSM, MPM, and MFD all utilizes a structured matrix approach used to decompose products. However the decomposition is made in different ways. MPM uses initialization and triangularzation, MFD clarify customer requirements in a Quality Function Deployment (QFD) matrix while DSM decomposes the system into elements. All methods become difficult to use when dealing with comprehensive products. To be able to use these methods the decomposition and integration must be done of several different levels of aggregation. However, MFD support modularization in complex product by providing a method for modularization downwards in the system levels (Ericsson & Erixon, 1999). All mentioned methods are based on functional decomposition of products and cluster into modules that form the product architecture. However it was realized that the various methods incorporated different parts of the product development process, Figure 6. The methods span over different part of the product development process and have different perspectives and focus. This realization was essential in selecting method for the product modularization part of the master thesis.

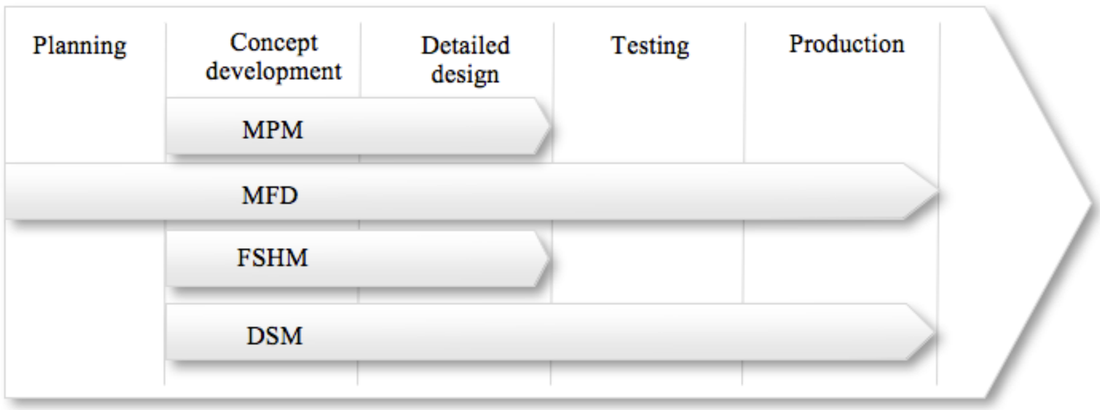

Figure 6 – Visualisation of the structure methods over a general product development process.

4.1.1 Modular function deployment

This thesis is partially based on the method MFD. MFD has a comprehensive theory background consisting of several books and articles discussing the method in different aspects. The method is based on functional decomposition of products to create modules. Since the project aims to create modularity in a company with limited experience in the area, it is important to investigate and understand the reason for modularity within Saab EDS, included in the whole product development life cycle.

MFD is based on a concept called module drivers to identify technical solutions (parts and sub-systems) with strong reasons for modularization, considering reason for departments included in the entire development life cycle (Ericsson & Erixon, 1999). The correlation between the module drivers and technical solutions are evaluated in a Modular Indication Matrix (MIM). The idea behind the methodology is to create modules by clustering parts or sub-systems that have similar reasons for modularity. As the purpose for this project was to investigate modularity in Saab EDS with existing configuration of the systems as a basis, no efforts in developing a QFD and finding alternative technical solutions were conducted. Also improvement activities and optimization of proposed modules are considered as future work. The areas of interest and alterations made to the method are presented in Figure 7.

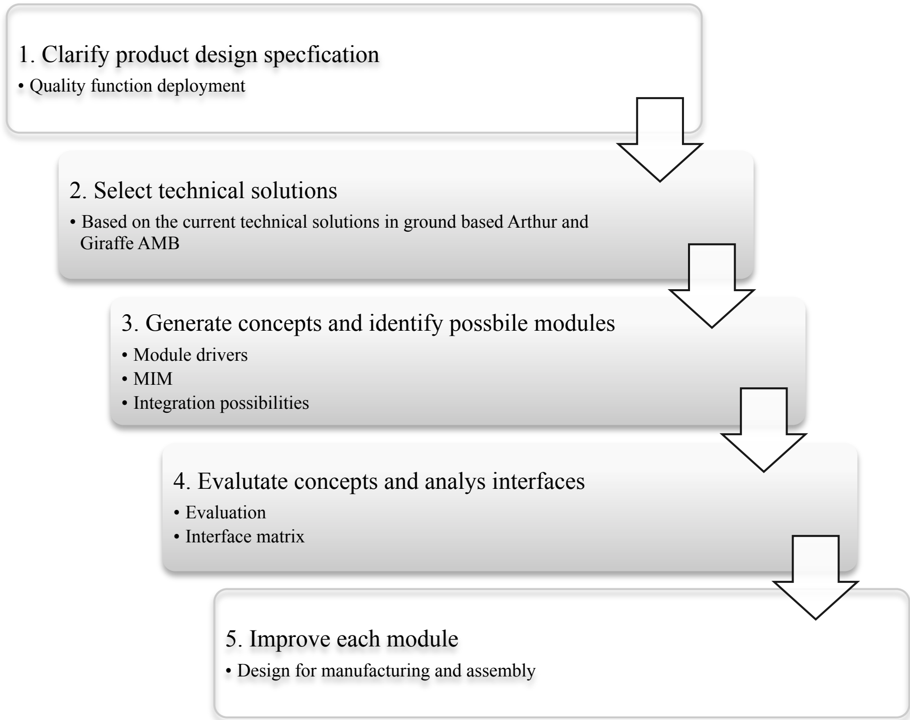

Figure 7 – MFD methodology for product modularization, areas of interest in this master thesis highlighted.

Literature argues (Ericsson & Erixon, 1999) that the decomposition into modules continues down in the system levels as long as it is considered meaningful. Hsuan (1999) presents a definition regarding modularization on different system levels:

System level: System level in this context are the product on highest level, the product are enclosed by sub-system with clear pre-defined interfaces.

Sub-system level: Sub-system is produced by assembling building blocks at module level.

Module level: Modules are created by a combination of different parts from the component level and are in this master thesis defined by decoupling at sub-system level.

Component level: This is considered the lowest level of modularization, represented by standard, off-the-shelf parts such as resistors, connectors, and screws. To benefit from economies of scale and shared components between systems it can be beneficial to proceed with modularization to the component level (Ericsson & Erixon, 1999).

4.1.2 Module drivers

Modules drivers are used as a decision-making tool when defining modules. The various module drivers are used to consider reasons for modularity at various departments included in the development life cycle. Technical solutions (parts and sub-systems) are assessed by modules drivers and provide an indication on how to defined modules. There are twelve module drivers according to the methodology and these are correlated to different department in the organization and are presented below with a definition according to Ericsson & Erixon (1999).

Development and design

Carryover	Parts or sub-systems that most likely will not be exposed to design changes during the life of the product should form a module.
Technology push	Parts or sub-systems that are likely to undergo changes as a result of changing demands or technology shift should form a module.
Product plan	Parts or sub-systems that the company consciously will develop should form a module.

Variance

Different specification	Parts or sub-systems that create variance and different specification should form a module.
Styling	Parts or sub-systems that create visual and virtual variance should form a module.

Manufacturing

Common unit	Parts or sub-systems that can be used in the entire product family should form a module.
Process and organization	Parts or sub-systems that have similar production or installation process should form a module.

Quality

Separate testing	Parts or sub-systems that have potential to undergo separate functional testing should form a module.

Purchase

Supplier availability	Parts or sub-systems that exist at sub-suppliers and vendors should form a module.

Aftermarket

Service and maintenance	Parts or sub-systems that demands recurring service and maintenance should form a module.
Upgrading	Parts or sub-systems that can be upgraded should form a module.

Recycling Parts or sub-systems that should be easily recyclable should form a module.

4.1.3 Module Indication Matrix

The correlation between the module drivers and technical solutions are evaluated with a MIM. It indicates which technical solutions have strong reasons for modularity called domination functions and which technical solutions could be clustered into the same module due to similar reasons. The MIM also indicates which of the module drivers are considered main drivers and should correspond to the company' reasons for modularity (Hölttä-Otto, 2005).

The procedure of the method is to examine every technical function individually deciding how strong the drive for modularity is on a scale; 9 (strong driver), 3 (medium driver), and 1 (weak driver). A general MIM is presented in Figure 8. Note how the main drivers carryover and common unit that received the highest amount for all technical solutions are highlighted in red in the analysis. The dominating functions (technical solution with strongest reasons for modularity) 5 and 7 are highlighted in green. Modules are preferably built around the domination functions with technical solutions that have the same reason for modularity; possibilities of this are highlighted in blue. With this example three possible modules could be formed and should be given attention for eventual integration possibilities. The first module could be composed by integrating technical solution 4 and 5, the second by integrating 3 and 5, and the third by 1, 2, 6, and 7.

Module drivers		Technical solution 1	Technical solution 2	Technical solution 3	Technical solution 4	Technical solution 5	Technical solution 6	Technical solution 7	Main Drivers
Development & Design	Carry-over	3			9	9		3	24
	Technology evolution		3	9		9			21
	Product plan		1	3			3		7
Variance	Different specification	3				3			6
	Styling		3		3		9		15
Manufacturing	Common unit	9	9				9	9	36
	Process & organization	3	1			3			7
Quality	Separate testing	3		3					6
Purchase	Supplier avaliability				1			9	10
Aftermarket	Service & maintanence		3			9			12
	Upgrading			1		3		9	13
	Recycling				3			1	4
	Dominating functions	21	20	16	16	36	21	31	

Figure 8 – An example of a Module Indication Matrix.

As seen highlighted in yellow a conflict appears on how to cluster technical solutions 3, 4 around the dominant function 5. MFD offers a tool to deal with these kinds of conflicts, which is based on a Pugh selection matrix (Erixon, et al., 1994). The different possibilities of module formation are investigated from a set of goals for the module architecture. In the example, opportunities to form three different modules arose. Could technical solution 4 and 5, 3 and 5 or 3,4 and 5 form a module? This scenario causes discussions and technical parameters to emerge and aggravate decision-making.

4.1.4 Interfaces

If the interfaces are well defined they will allow for flexible product architecture. When starting working with interfaces of the modules it is fundamental the product architecture is decided upon because different architectures will have different interface specifications (Pimmler & Eppinger, 1994).

To be able to create module interfaces feasible for the whole company there are a vast amount of factors to consider when deciding upon the interfaces of a new architecture. Sanchez and Mahoney (1996) emphasize the importance of consider coordination of complexity when structuring the interfaces. An important factor to consider is the duration interfaces cannot be changed. In order to uncouple the modules, interfaces cannot be changed during critical periods in the life cycle of the module.

Another important factor regarding interfaces is how they are managed within the company. At Volvo Trucks AB, interfaces are divided in three levels depending on importance of the interface. Depending on the level, decision to change the interface must be done by persons on different hierarchical levels in the organization (Pasche, 2007).

To be able to take decisions regarding module interfaces on different organizational levels in the company organizational learning is crucial. When implementing modularization into organizations new knowledge architectures must be built in order to understand how the specification of interfaces influence the rest of the organization. Sanchez (2000) uses the expression *architectural-level knowledge* to incorporate knowledge about cause and effect relationships between components. When the products are integrated, it can be difficult to understand all activities influencing connections between components. By creating modules, that are loosely coupled, new *knowledge domains* are created. The *knowledge domains* create knowledge both on an organizational as well as on a component level (Sanchez, 2000). Another factor to consider regarding modular interfaces is communalization patterns. Standardized interfaces of modules create a loosely coupled organizational structure (Sanchez & Mahoney, 1996). Currently the integrated product architecture leads to time-consuming activities of communication between projects and departments.

MFD provides a tool that gives a good overview of the interface relations called the interface evaluation matrix and is presented in Figure 9. The modules derived from the MIM and selection matrices are placed in the left column according to their expected assembly order, the interrelation are marked accordingly:

- G for geometrical interfaces between modules
- E for energy transmitting interfaces between modules

However it is important to note that only interfaces between modules are considered, hence interface within modules are not taken into consideration.

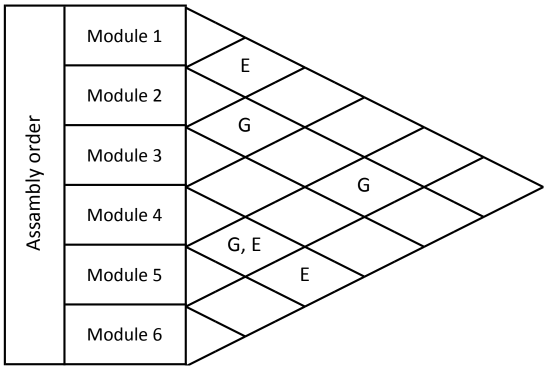

Figure 9 - Interface evaluation matrix.

That the interfaces should be categorized into different areas are well accepted in the literature studied. However Sanchez and Mahoney (1996) expand the classification of interfaces and suggest the following categories:

Attachment -	Interfaces describing the physical connection of the module in relation to other surrounding components.
Transfer -	Interfaces describing the power supply and distribution of the module.
Control and communication -	Interfaces describing how the module should be controlled for easy fault detection.
Spatial -	Interfaces describing the spatial geometry that the product occupies.
Environmental -	Interfaces describing how the surrounding environment in the form of for example heat, magnetic fields affects the module.

4.2 Organization

According to Sanchez and Mahoney (1996) the product- and organization architecture are strongly correlated. They emphasize that integrated product architectures most often is combined with a coupled organization structure with a strict management authority hierarchy. An important factor to consider when analyzing the organization is according to Rubenowitz (2004) the number of organizational levels. He argues that a deep organization structure leads to a constant need for communication cross projects resulting in complex communication. The complex communication extends development time and managerial coordination. Rubenowitz (2004) also emphasize the correlation between organization structure and the organization efficiency.

One organization form important for this study is the matrix organization. A matrix organization requires managers to keep the system together resulting in high organizational costs, coordination and power struggle (Davis & Lawrence, 2009). According to von Hippel (1990) a development task depending on other development tasks requires managerial coordination and thus consumes a lot of resources.

Another important factor is the product architecture. An integrated product architecture results in tightly coupled components and as a consequence a coupled organization (Sanchez & Mahoney, 1996). Integrated product architecture is in many cases the result of a reactive development strategy. Wheelwright and Clark (1992) argue that in reactive development projects up to 60-70 percent of the development resources are consumed sustaining projects or activities.

In a modular product architecture with loosely coupled components the need for managerial authority is less important and also the organization can be loosely coupled. Sanchez and Mahoney (1996) express it, as modular product architecture is the glue holding together the loosely coupled organization design. They express it as a loosely coupled organizational design creates flexibility and decreases the need for managerial authority.

A defined information model manages the communication between module teams in an organization. The interfaces of the modules are defined in detail and fixed during a period of time in the development process thus creating an information model. Well-defined interfaces will result in less need for managerial coordination and thus shorten the lead-time when developing new products. But there are also opponents to that way of thinking. Brusoni and Prencipe (2001) argue that the mapping between the modular organization and product architecture actually requires coordination and thus managerial activities.

The information model minimizes the risk of sub-optimization but not overall optimized products (Sanchez & Mahoney, 1996). Sköld and Karlsson (2007) also emphasize the information aspect but especially in the form of big managerial challenges of commonality and distinction when working with multi-branded platforms. They divide the managerial challenges into three main parts; technology-, brand-management and general management.

To be able to work according to a modular product architecture all functions within the company needs to work according to predefined interfaces. It is therefore essential that the product architecture be structured to handle the customer demands. The communications patterns from the market to the product development function must be further developed to increase know-why knowledge on lower system level (Sanchez, 1996). Brown and Eisenhardt (1995) conclude that a structured task communication results in higher efficiencies in all parts of the product development processes.

To be able to uncouple the organization and map it against the product architecture module teams is a solution. Volvo Cars and Chrysler have adopted cross-functional module teams, Figure 10. In the case of Chrysler the module teams are placed at certain places in the office building to minimize waste activities (Persson, 2011).

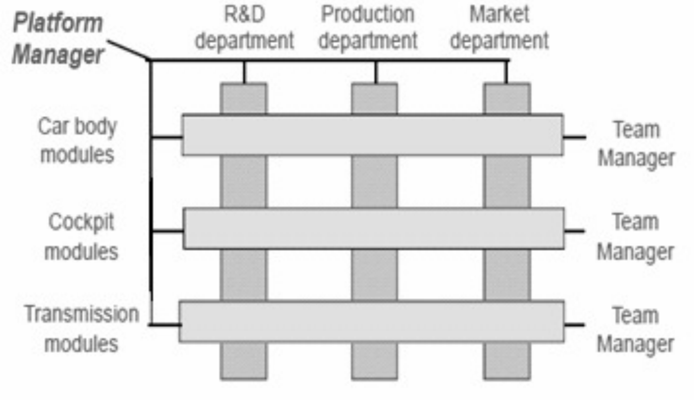

Figure 10 - Cross-functional module teams at Volvo Cars (Persson, 2011).

A modular organization enables development work to be performed in geographically dispersed areas and creating component variation and thus improving the product variation. By partition tasks into organizational modules, work can be done concurrently and autonomously. Doing the work autonomously and concurrently put high demands on flexibility in work which Sanchez and Mahoney refer to as *resource chains*. The chains can quickly link together the organizations resources and capabilities. The ability to coordinate several organizations together if needed leads to faster development, broader knowledge and cost reductions. Von Hippel (1990) also argues that cost reductions can be reached if the task is portioned in an effective way, which minimizes the cost for cross boundary problem solving.

4.3 Cost effects and customer adaptations

A modularization strategy affects all parts of the organization in the entire product life cycle (Ericsson & Erixon, 1999). A modular architecture decouples different units of a product by standardized interfaces, making them independent from each other. Having predefined interfaces between modules reduces the need for information exchange. The need for communication is reduced since designers can be certain that development and modifications are accepted if the standard interfaces are respected (Ulrich & Tung, 1991). According to Baldwin and Clark (1997) the rate of innovation rapidly increases by sub-specialization in specific clearly delimited areas. By increasing the rate of innovation a modular architecture also enables to accelerate the change of pace, thereby always creating products with high customer value.

By using modules on different systems level the organizational barriers can be limited if the designers, on different systems push instead of pull technology according to customer orders (Ulrich & Eppinger, 1999). Concurrent modular engineering leads to reduce development lead-time. A result of the shortened lead-times in development is reduced capital tied up in stock as well as product and manufacturing plans can be broken down into module specific goals (Erixon, et al., 1994). According to Kalmbach (2005) the development cost will be reduced since the development cost of a single product is spread over several systems.

4.3.1 Cost effects of modularization

A modular approach emphasis clearly defined standardized interfaces allowing variation but at the same time not endanger the system as a whole. The key for a cost effective modularization is to maintain standardized interfaces. Literature argues that a modular design influence costs in the entire product lifecycle. Thyssen, et al. (2006) comprises a set of sub categories for different parts of the value chain that is influenced by a modular strategy.

- Design cost
- Procurement overhead cost
- Production overhead cost
- Quality cost
- After-sales and service cost

The categories correlated to cost reductions are reflected in the partitioning of the MFD concept module drivers, which are included in this analysis and presented in Figure 11.

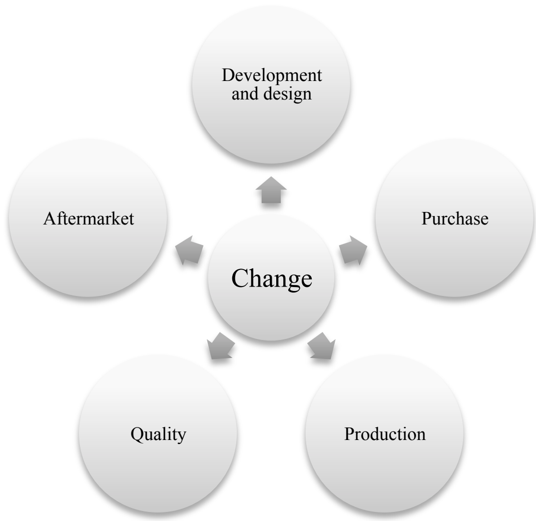

Figure 11 - Change effects in the product life cycle.

Modular product architectures are flexible and consequently modular product constitutes an important source of flexibility (Sanchez, 1995). Firm can react quickly to market demands and technical innovations since the loose organizational coupling allows for continuous change. However the system should be prepared for possible options (Zhou & Grubbström, 2003), this can be done by over specification to prepare the system for various altering demands.

Development and design

A basic rationale for modularization is shortened development lead-time is shortened and costs are reduced (Ulrich & Tung, 1991). This is connected to product development as modularization enables a cost effective product development (Pasche, 2011). Modularization enables loosely coupled organizational structures allowing concurrent, autonomous and decentralized product development processes (Sanchez, 1996).

Cost for development and design will decrease as the volume of design is reduced when shifting from a number of unique components to one component. If the interfaces are standardized, re-assembly in both the physical product and the product architecture is reduced. As long as the design rules are met, module innovation will not demand changes in other parts of the system (Baldwin & Clark, 1998).

Purchase and procurement cost

Literature argues that modularization provides opportunities for economies of scale (Thyssen, et al., 2006) meaning that purchasing in larger quantities could lower the cost per part. Modularity provides opportunities to outsource complete modules in a black-box engineering approach (Ericsson & Erixon, 1999). Black-box engineering provides opportunities to utilize suppliers that can manufacture parts or sub-systems to a lower price. However modularization requires the need for maintained supplier relations and move toward partnership with key suppliers (Hsuan, 1999).

Production cost

Modularity supports a decoupling of task in manufacturing (Pasche, 2011). Modules constitute the system and are assemble in the system with well-defined interfaces. Dividing a product to independent components allows production activities to be specialized and focused (Ulrich & Tung, 1991). Modularity will lead to a decrease in cost as fewer material handlings and set-ups are required (Kaplan & Cooper, 1998) and the assembly could be planed in a cost efficient way.

Quality cost

The cost of quality is reduced with a modular strategy. Fisher, et al. (1999) argue that quality will increase due to learning and quality improvements associated with increased volume. A modular architecture could better utilize the same testing procedures as described by Ulrich & Tung (1991). The quality of the products in modular product architecture will be higher since it can be tested across several designs (Kalmbach, 2005).

After-sales and service cost

A modular strategy reduces the inventory cost as modules are designed for the entire product portfolio (Thyssen, et al., 2006; Zhou & Grubbström, 2003). Modules could be stored to function with different projects. Modular products can be easily upgraded and serviced throughout the product life cycle (Brusoni & Prencipe, 2001), lowering the cost of after-market activities.

4.3.2 Customer adaptations

Customer adaptations are a part of the base line product, Figure 4. A cost calculation is performed in the thesis considering costs as a measure of changed interfaced due to customer adaptation in modular product architectures. The cost can be calculated in a vast variety of ways using different methods. Frequently mentioned methods in literature are Activity Based Costing (Aniander, et al., 1998), Target costing (Ehrlenspiel, et al., 2007) and Absorption costing (Foster, 2008).

The thesis is based on ABC since the estimations can be done early in the development process, has a comprehensive theory background with development focus and the costs are easily correlated to different activities within various departments of the company. The disadvantage with the method is that it potentially can allocate excessively many expenses to a single product (Glaumann & Gustavsson, 2002).

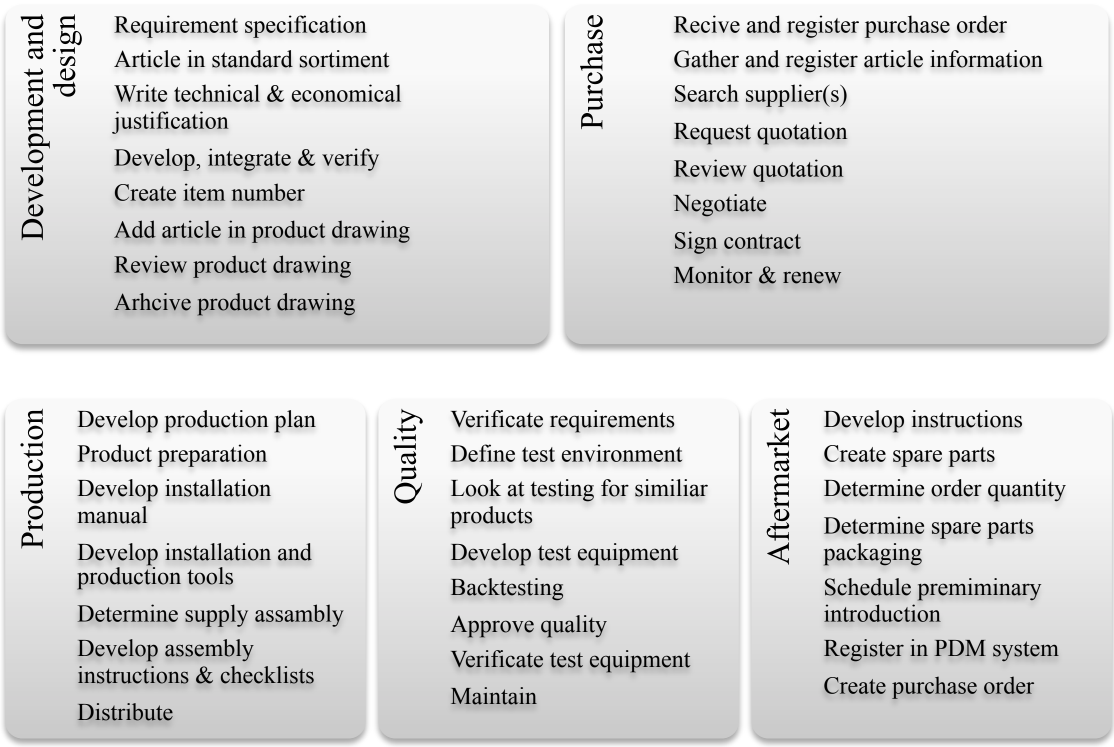

Figure 12 - Example of activities in the product life cycle.

ABC analysis divides the cost for processes on different system level in a company to activities and assigns costs to the activities (Glaumann & Gustavsson, 2002). The information of cost drivers is collected from the entire product life cycle, Figure 12.

5 Results and Analysis

In the following chapter the result and the analysis of the products, organization and cost assessment are presented. Different methods derived from literature are complied into a Saab EDS specific method for modularization. Modules are defined according to the MFD methodology and interfaces standardized and classified for both Arthur and Giraffe AMB. Further organizational implications are considered and changes proposed to the organization, in order to account for the benefits discussed in literature. A framework for estimating costs due to customer adaptations and that changes the standardized interfaces.

5.1 Modularization of the products

Literature (Ericsson & Erixon 1999) emphasizes the importance of senior management involvement when implementing modularization. The work needs to done by experienced senior engineers and product managers with profound product knowledge. The following assessment regarding product modularization in this chapter is conducted in collaboration with experienced engineers and documentation regarding the product properties as support. The result should be analysed from different angles and the assessment should be revised before realization.

Modularization of Saab EDS current ground based systems Arthur and Giraffe AMB will continue with a sub-set of the MFD methodology, explained in chapter 3. The defining of modules is conducted in three steps beginning at sub-system and end at component level according to the framework presented by Hsuan (1999). The analysis will include a subset of the systems since the purpose is to provide Saab EDS with a methodology applicable for modularization and not to perform a modularization of the complete systems.

5.1.1 Selection of technical solutions

The identification and selection of technical solutions possible for modularization were determined by investigating current product structures at Saab EDS. The product structure is hierarchical with decomposed functional areas that form the system. It was noted that the product structure for Arthur, Figure 13, and Giraffe AMB, Figure 14, differed in the architecture and was not build up around an identical framework.

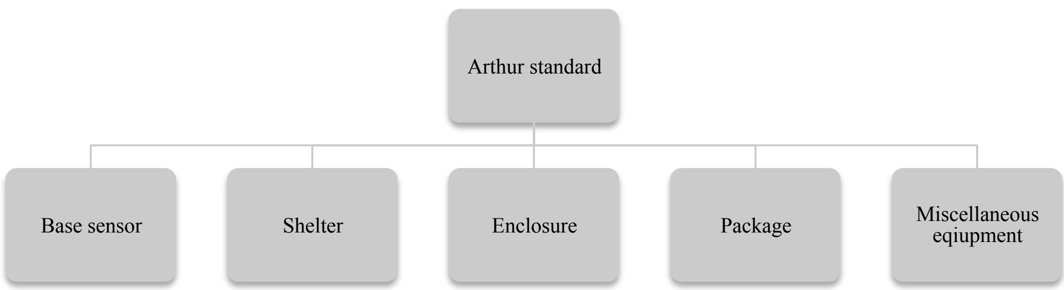

Figure 13 - Product structure for Arthur standard.

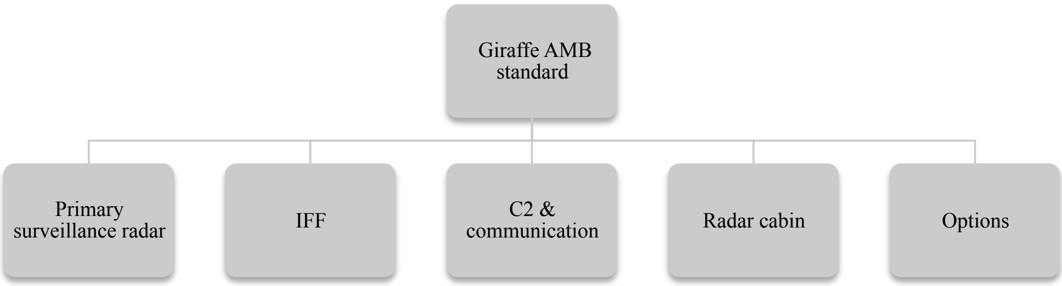

Figure 14 - Product structure for Giraffe AMB standard.

The analysis will be concentrated to technical solutions incorporating the same functional areas within both systems. The product structure is not equal for the systems but similarities and analogies can be derived. Two examples of such analogies are the parts base sensor/primary surveillance radar and enclosure/radar cabin.

According to the MFD methodology this will be done by a set of modules indication matrices, MIM. In the module assessment the two systems Arthur and Giraffe AMB are separated. A set of MIM is conducted per system at every system level. Before the assessment is made it is important to define the module drivers and apply these to the Saab EDS situation.

5.1.2 Module drivers

MFD according to Ericsson & Erixon (1999) offers a general description of the concept module drivers and how they are supposed to be interpreted in a MIM context. Module driver definitions stated by Ericsson & Erixon (1999) are presented together with clarification of the module drivers to comply with the company situation. Further sources used in the module driver assessment are presented.

Carryover

A carryover module is a part or a sub-system of a product that most likely will not be exposed to design changes during the life of the product platform. The part or sub-system can therefore, be carried over from an earlier product generation.

In the company context carryover will be considered as part or sub-system from previous customer projects that have opportunities to be carried over directly to future customer projects. This was mainly derived from the standard product structure available for the two products and Base Line Product documentation. However a clear distinction is made, carryover is considered between the products individually, and does not consider carryover from for example a previous Arthur project to a future Giraffe AMB project.

Technology push

Technology push refers to parts that are likely to undergo changes as a result of changing customer demands or technology shift. The technology itself can evolve or new materials might be made available.

To derive which parts and sub-system that are exposed to technology evolution interviews were performed with product managers and Product Revision Information (PRI) was investigated. Further the product managers answered for which sub-systems that historically have been changed in a rapid pace due to changed customer demands or technology shifts.

Product plan

Planned product changes concern parts of the product that the company intends to develop and change. These changes may be carried out to launch new product models, better fulfil certain customer demands or decrease production costs.

Product plans for the two systems currently does not exist at Saab EDS. However, planned development activates on part or sub-systems can be derived from PRI and product definitions for the base line products Arthur and Giraffe AMB.

Different specification

To handle product variation and customization effectively, a designer should strive to allocate all variation to as few product parts as possible. It is also advantageous to make the variation adaptation as late as possible in the production chain to improve inventory savings, customer service, and to lower the overall costs.

In the Saab EDS context different specification is allocated to parts and sub-system that are outside the Base Line Products structure. Primary these parts and sub-systems exist as customer standard options and are located by investigation Base Line Product documentation.

Styling

Some parts of the product may be strongly influenced by business trends, or closely connected to a brand or trademark. Therefore, styling modules that typically contain visible parts of the product should be used to underline product identity.

The need to adapt to military trends is minimal. The only form of styling that exists in the ground based radar systems is different painting options (colour and camouflage) on exterior parts and adapt to customer environments.

Common unit

Although a high degree of customization requires many product variants, it is possible to find parts or subsystems that can be used for the entire product assortment or large parts of it.

Currently the two systems are defined as two independent product families, both in terms of application, development and within the organization. As the purpose for the master thesis includes an investigation regarding opportunities for shared modules between Arthur and Giraffe AMB these two systems will be considered to belong to the product family ground based radar system. Opportunities for common modules will be investigated in current product structures for the two systems, aiming to find item number identical parts or sub-systems that could possibly be defined as a shared module.

Process and organization

To make production as efficient as possible, parts of the product requiring the same specific production processes are clustered together.

Process and organization is not the main areas for this master thesis and are only briefly considered. Processes are exclusively considered if the part is manufactured in-house or outsourced and the scaling is done regarding the degree of in-house processing. Parts or sub-systems manufactured complete in-house are discovered in Saab EDS, PDM system IFS.

Separate testing

The possibility to separately test each module before delivery to final assembly may contribute to significant quality improvements.

In Saab EDS the norm is to test sub-systems before system installation, derive from internal test documentation. This makes it difficult to account for effects by creating separate testable module. However a demand on the new modular product architecture is to allow for testing at module level. Some opportunities remains in creating standardized test rigs that incorporate current sub-systems in the same testing procedure.

Supplier availability

Instead of buying individual parts from subcontractors, some subsystems in the product are bought as standard modules from vendors. This black-box engineering principle implies that the vendor takes a total responsibility of the module both regarding manufacturing, development, and quality assurance.

In Saab EDS black-box engineering principle already exists, concerning the power plant, hydraulic component and GPS unit. They often bought directly from a vendor who also has responsibilities for the development and quality. However the usual practice is in-house development and outsourced manufacturing. Parts or sub-systems purchased from supplier are discovered in Saab EDS, PDM system IFS.

Service and maintenance

Quick service and maintenance in the field is often an important customer requirement. Therefore, parts exposed to service and maintenance may be clustered together to form a service module.

To identify parts and sub-systems in both Arthur and Giraffe AMB that needs to be maintained or replaced, documentation from ILS will be studied to derive parts that should form service and maintenance modules.

Upgrading

Designing a module to allow for upgrading offers the customers the possibility of changing the product in the future.

In Saab EDS parts and sub-systems that are adapted to cope with possible future upgrade are derived from documentation of the Base Line Products. In the case of upgrading it is important not to combine hardware and software. Since software requires continuous upgrades it will not included.

Recycling

There is a growing interest in environmental issues and the emphasis on sustainable design increases.

To enable a high degree of recycling the number of different materials in modules should be limited. Hostile and easily recyclable should be kept separate in specific modules so that disassembly and disposal will be simplified. For Saab EDS recycling is not of significant importance and will not be a part of the subsequent analysis.

5.1.3 Sub-system level

The practical analysis of the product modularization will decouple the systems top down according to the system level definitions provided by Hsuan (1999). System level is the highest level and is in the Saab EDS case translated as the systems Arthur and Giraffe AMB. To decompose the two systems at system level, functional areas with correlated technical solution was derived from product definitions, for the two systems separately. To be consistent in the analysis a scale definition connected to the module drivers was issued to serve as a framework in the assessment, Appendix 2. The MIM assessment of sub-system level is presented in Figure 15 for Arthur and Figure 16 for Giraffe AMB.

		1	2	3	4	5	6	7	8	9	
Module drivers	Functional areas	TRU	SDU	Antenna	CDU	Cabin	Cooling system	Power system	DU (HMI)	Turntable system	
Development & Design	Carryover					9	9	3	3	3	27
	Technology push				3				3	3	9
	Product plan	9	9	9				3			30
Variance	Differnt specification				3			3	9		15
	Styling			3		3				3	9
Production	Common unit	3	3				3	3	3		15
	Process & organisation	3	3					3			9
Quality	Separate testing	3	3	9					3		18
Purchase	Supplier avaliability				9	9	9	3	9	9	48
Aftersales	Maintanence & Service	3	9	3	3		3	3		3	27
	Uppgrading		1					3	3		7
		21	28	24	18	21	24	24	33	21	

Figure 15 - Sub-system level MIM for Arthur.

	ID:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Module drivers	Functional areas	Antenna	TRU	SDU	Turntable system	HMI (DU)	Cabin	Mast	Support legs	Power plant	Cooling system	Hydraulic system	DAU	NBC unit	GPS	Power system	
Development & Design	Carryover	9		3	3	3	9	3	3	3	9	9	3	3	3	3	66
	Technology push				3			3	3				3		3		15
	Product plan		9	3		3				3	3					3	24
Variance	Different specification					9	3						3		3	3	21
	Styling	3			3		3	3	3								15
Production	Common unit		3	3		3					3			9		3	24
	Process & organization		9	9												9	27
Quality	Separate testing	9	3	3													15
Purchase	Supplier avaliability				9	3	9	3	9	9	3	3	9	9	9		75
Aftersales	Maintanence & Service	3		9	3					9	3	3				3	33
	Uppgrading			1		3				3	1					3	11
		24	24	31	21	24	24	12	18	27	22	15	18	21	18	27	

Figure 16 - Sub-system level MIM for Giraffe AMB

In Figure 17 for Arthur and Figure 18 for Giraffe AMB the normalized assessment is shown. The normalized assessment is used to identify areas with strong or very strong reasons to form a separate module. Areas with weak reasons can be suited for integration. It was realized that integration at this level should be considered secondary. The current systems have a clear composition of sub-systems and the reason to integrate sub-systems into a module needs to be further analysed.

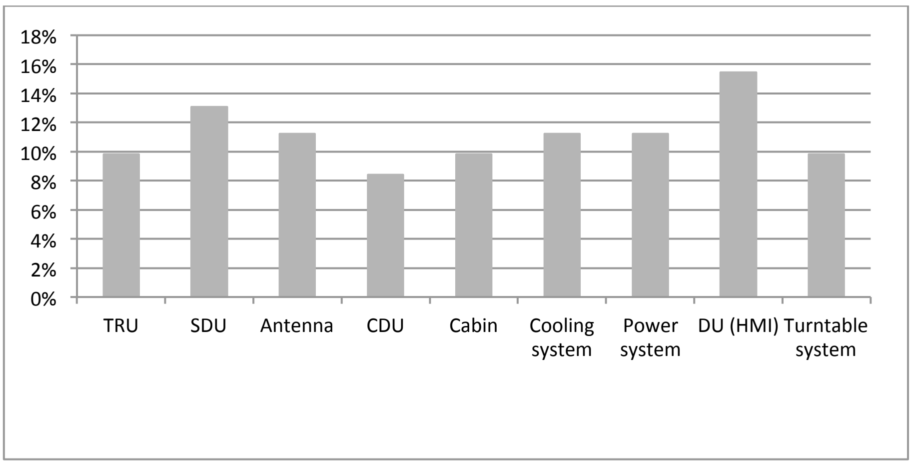

Figure 17 – Arthur sub-system module driver profile

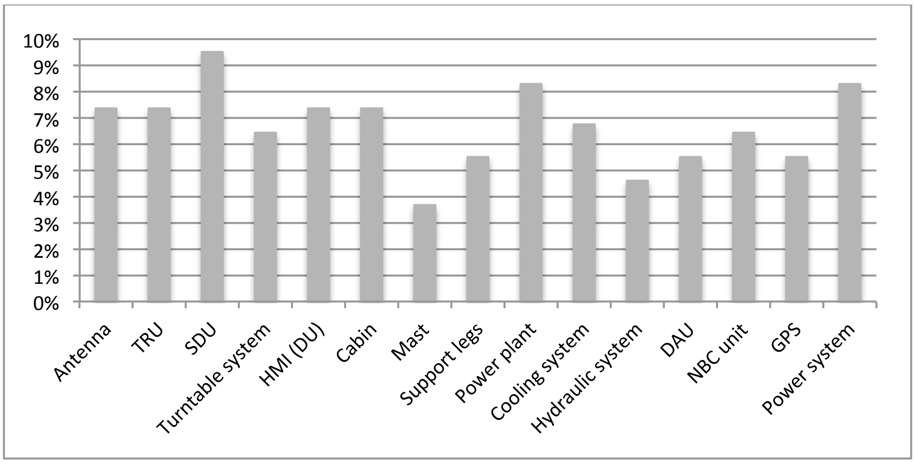

Figure 18 - Giraffe AMB sub-system module driver profile

A conclusion that can be drawn from the sub-system level assessment for Arthur and Giraffe AMB is that functional areas most often demonstrate high reasons to form separate modules. An example is the power plant that should form a module due to the carryover and supplier availability properties. Since the power plant is a supplier module, further decomposition is not considered meaningful. Table 1 for Arthur and Table 2 for Giraffe AMB summarize the result of the analysis, derived functional modules that have strong reasons to form a separate module and integration possibilities present.

Table 1 - Arthur sub-system level modules

Module	Strongest driver	Variants	Technical solution
M1 TRU	Product plan	1	TRU
M2 SDU	Supplier avaliability Product plan Maintanence & Service	1	SDU
M3 Antenna	Product plan	1	Antenna
M4 Power system	Product plan	1	Power system
M5 Cabin	Carryover Supplier avaliability	1	Cabin Turntable system
M6 DU	Different specification Supplier avaliability	1	DU CDU
M7 Cooling system	Product plan Common unit	1	Cooling system

Table 2 - Giraffe AMB sub-system modules

Module	Strongest driver	Variants	Technical solution
M1 Antenna	Carryover Separate testing	1	Antenna
M2 TRU	Product plant Process & organisation	1	TRU
M3 SDU	Maintanance & service	1	SDU
M4 Power system	Process & organisation	1	Power system
M5 Turntable system	Supplier avaliability	1	Turntable system Mast
M6 HMI	Differnt specification	1	HMI GPS
M7 Cabin	Carryover Supplier avaliability	1	Cabin Support legs NBC unit Hydraulic system
M8 Power plant	Product plan Supplier avaliability Maintanance & service	1	Power plant
M9 Cooling system	Carryover	1	Cooling system DAU

A summation of the module drivers from the MIM is normalized in Figure 19, showed how each factor was weighted. The module driver profile should serve as a basis for discussions regarding strategies, competencies and vital technologies (Ericsson & Erixon, 1999). It should be observed that the wish to re-use modules and increase the pay-off on technical solutions already developed is reflected. Further supplier availability is the second largest driver, reflection on the fact that substantial parts of the system are dependent of the supplier relationship.

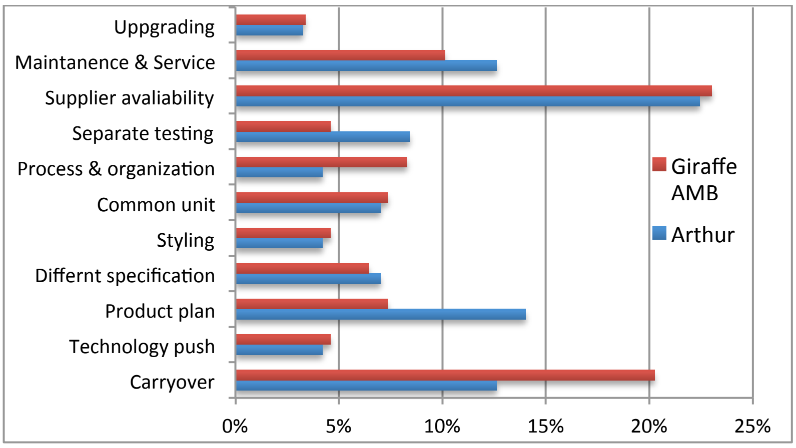

Figure 19 - Module driver profile

It was also observed how the same functional areas had different properties and the module driver product plan and carryover does not reassemble each other in the assessment. This could be reflected in the current development procedures and that customer projects does not occur simultaneously.

5.1.4 Module level

The power system was chosen as the only part to be further analysed for modularization on lower system levels. The reason for choosing the power system is a request from Saab EDS. The power system, is in the current configuration is build with a set of technical solutions that could be defined as modules it was subsequently chosen. Two MIM analyses were performed to define modules depending on the properties of the technical solutions. The MIM assessments for the power system for Arthur is seen in Figure 20 and for Giraffe AMB seen in Figure 21. Technical solution with strong reasons for modularity was derived and other parts where considered for integration if the module drivers were similar.

	ID:	1	2	3	4	5	6	7	8	9	10	
Module drivers	Technical solutions	PDU1 230V	PDU2 28V	Power plant	LPU	PU 1	PU 2	Battery unit	Battery charger unit	PCP	PIP	
Development & Design	Carryover	9	9	9				3	3	9	3	45
	Technology push							3	3			6
	Product plan				9						3	12
Variance	Different specification					9	9				3	21
	Styling										3	3
Production	Common unit	3	3			1	1	9	9	1	3	30
	Process & organization	9	9			9	9					36
Quality	Separate testing	3	3			3	3					12
Purchase	Supplier avaliability			9				9	9		3	30
Aftersales	Maintanence & service	9	9	9	9	3	3	3	3		9	57
	Uppgrading			3		1	1	9	3	3	3	23
		33	33	30	18	26	26	36	30	13	30	

Figure 20 - Arthur module level MIM

	ID:	1	2	3	4	5	6	7	8	9	10	11	
Module drivers	Technical solutions	PDU1 230V	PDU2 28V	LPU	PU1	PU2	PU3	PU4	Battery unit	Battery charger unit	PCP	PIP	
Development & Design	**Carryover**	9		3	9	9			3	3	9	3	48
	Technology push								3	3			6
	Product plan		9	3								3	15
Variance	**Different specification**	3	3				9	9			9	3	36
	Styling											3	3
Production	**Common unit**	3	3	9	3	3			9	9		3	42
	Process & organisation	9	9		9	9	9	9					54
Quality	**Separate testing**	3	3									3	9
Purchase	**Supplier avaliability**								9	9	3	3	24
Aftersales	**Maintanence & service**	9	9	9	1	1	1	1		3		9	43
	Uppgrading				1	1	1	1	9	3	3	3	22
		36	36	24	23	23	20	20	33	30	24	33	

Figure 21 - Giraffe AMB module level MIM

Modules defined as a result from this assessment can be seen in Table 3 for Arthur and Table 4 for Giraffe AMB. Notable is that the power plant is located at different places in the product structure for the standard products. At this stage it was intentionally neglected to secure a one-to-one mapping between the analysis and Saab documentation regarding the standard product.

Table 3 - Arthur module level

Module	Strongest driver	Variants	Technical solution
M4.1 PDU	Carryover Procces & organisation Maintanence & service	2	PDU1 PDU2
M4.2 Power plant	Carryover Supplier avaliability Maintanence & service	1	Power plant
M4.3 LPU	Product plan	1	LPU
M4.4 PU	Different specification Process & organisation	2	PU1 PU2
M4.5 Battery unit	Common unit Supplier avaliability	1	Battery unit Battery charger unit
M4.6 PCP	Carryover	1	PCP
M4.7 PIP	Maintanence & Service	1	PIP

Table 4 - Giraffe AMB module level

Module	Strongest driver	Variants	Technical solution
M4.1 PDU	Procces & organisation Maintanence & service	2	PDU1 PDU2
M4.3 LPU	Product plan Procces & organisation		LPU
M4.4 PU	Different specification Process & organisation	4	PU1 PU2 PU3 PU4
M4.5 Battery unit	Common unit Supplier avaliability	1	Battery unit Battery charger unit
M4.6 PCP	Carryover	1	PCP
M4.7 PIP	Carryover Maintanence & Service	1	PIP

5.1.5 Component level

Until this part of the practical analysis it has been difficult to define modules that could be shared between Arthur and Giraffe AMB. But literature suggests (Ericsson & Erixon, 1999) that opportunities for shared modules and effects of economies of scale are located at component level. Therefore the analysis was proceeded by examine the PIP further. Component included in the analysis for the PIP are seen in Appendix 3.

	ID:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Module drivers	Technical solutions	Circuit breaker	Switch	Switch	Switch	Emergency switch	Power plug	Power plug	Frame	Sheat metall	Fixed sleeve	Fixed sleeve	Voltage relay	Holder	Holder	Bolt	Contactor	Contactor	Contactor	Relay	Filter	Filter	Illumination	
Development & Design	Carryover								9	9														18
	Technology push																							0
	Product plan																							0
Variance	Different specification	3					3																	6
	Styling								3															3
Production	Common unit	9	9	9		9	9	9			9		9			9		9		9	9		9	117
	Process & organization								9	9														18
Quality	Separate testing																							0
Purchase	Supplier avaliability	9	9	9	9	9	9	9			9	9	9	9	9	9	9	9	9	9	9	9	9	180
Aftersales	Maintanence & Service	3																						3
	Uppgrading																							0
		24	18	18	9	18	21	18	21	18	18	9	18	9	9	18	9	18	9	18	18	9	18	

Figure 22 - Component level MIM for the power inlet panel

As stated before the two systems Arthur and Giraffe AMB are not designed the same. Therefore it is assumed that the PIP as a whole cannot be shared between the systems. But there are opportunities to create modules of components that exist in both systems. The PIP was decoupled on component level to investigate the possibilities to create shared modules inside the PIP. From the MIM shown in Figure 22, it was realized that there are opportunities for shared modules on component level even though the PIP for Arthur and Giraffe AMB as a whole are not identical. The result of the assessment for Giraffe AMB on component level is shown in Table 5. Module M2 consists only of components that are identical for the PIP in both systems and should ideally form a module. At component level there are opportunities for reducing the number of components and identical modules.

Table 5 - Component level module Giraffe AMB

Module	Strongest driver	Variants	Technical solution
M4.7.1 Carryover	Carryover Process & organization	1	Frame Sheat metal
M4.7.2 Common unit	Common unit Supplier avalibility	1	Circut breaker Switch Switch Emergency switch Power plug Power plug Fixed sleeve connect Voltage relay Bolt Contactor Relay Filter Illumination
M4.7.3 Supplier	Supplier avaliability	1	Switch Fixed sleeve connect Holder Holder Contactor Contactor Filter

5.1.6 Modular product structure

To summarise the result from the analysis two separate product structures for Arthur, Figure 23 and Giraffe AMB, Figure 24 is presented. The structures cannot be seen as complete product structures for the respective systems but illustrate what the method can do. Notable is that the power plant (M8) has changed position in the structure for Giraffe AMB to create a resemblance in structure.

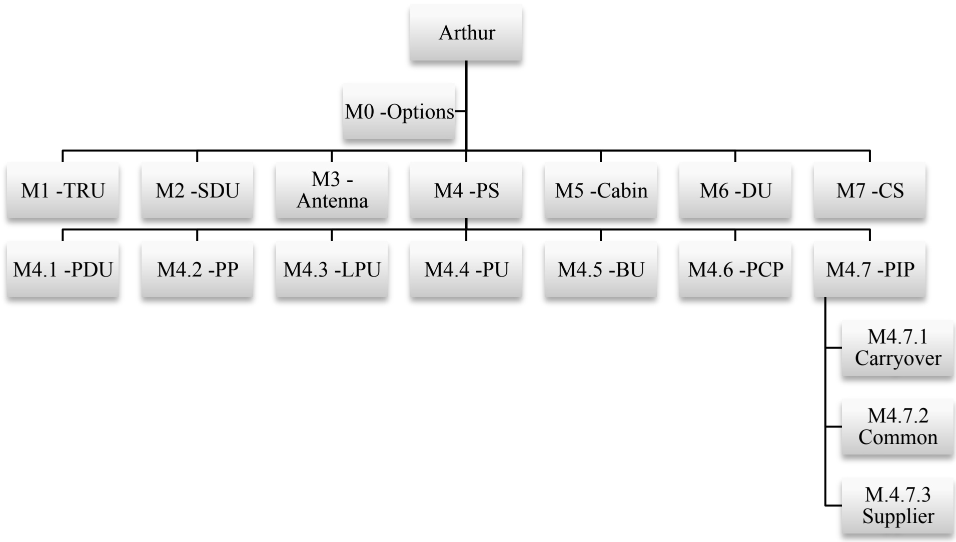

Figure 23 - Module product structure Arthur

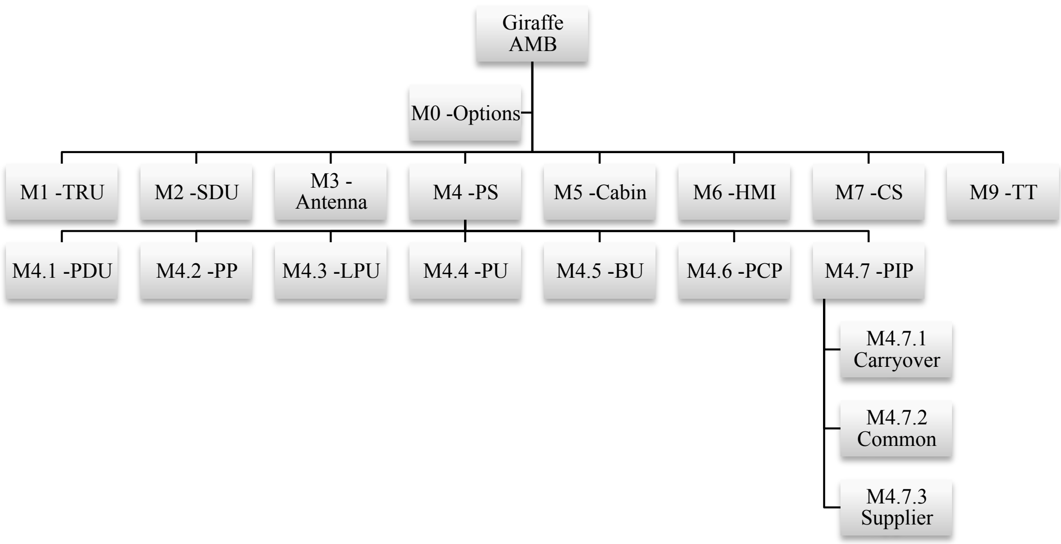

Figure 24 - Module product structure Giraffe AMB

5.1.7 Customer standard options

The Saab EDS base product strategy suppose to allow for customization and variance by offer the customer so called standard options, located as M0 in the product structure. This has been given little attention in the previous analysis, however it cannot be neglected. Options needs to be defined as module with clear interfaces and the products should in an easy way be able to integrate these option without effecting the system as a whole. Literature discusses the over specification trade-off (Thyssen, et al., 2006), meaning over specification of the system to enable standard customer options. In this case over specification should be considered as a mean to secure a stable system over time.

5.2 Product interfaces

A part or sub-systems cannot be defined as a module before interfaces are standardized. Saab is currently utilizing commonality principles for a few components between Arthur and

Giraffe AMB. When implementing a modular architecture commonality can lead to over specification of both the specification of the module but also of the modules interfaces. The company must for each module make a trade-off between the benefits of modularization and the risk of over specifying the product and disregard the modularization or disregard commonality for the module (Zhou & Grubbström, 2004).

A cross-functional group, including senior experts and senior specialists from different functions within the company, must decide the technical specification for the interfaces. One of the essential tasks for the cross-functional group is to decide how the specification should be made to last in the future. Some interfaces must be over specified and some modules need to have interfaces not used in all projects. Below follow an example of a composition of a cross-functional group at Saab EDS:

ILS:	Accounts for maintenance-, user, and stock activities influencing the interfaces of the module.
Production:	Accounts for possibilities and constraints in the production.
Product management:	Accounts for the future plan for the product and how what influence the interface specification and the technical details of the module.
Product development:	Accounts for technical competence regarding influence of development tools on interface specifications.
Sourcing and supply:	Accounts for the influence of testability, logistics and sourcing from the other parts of the Saab organization on the interface specification.

5.2.1 Interface evaluation matrix

To get a schematic overview of the interfaces of a module identified in the MIM an interface evaluation matrix from the MFD method is used. The interface matrix maps the most crucial interfaces between the modules at a certain system level. To keep the overview perspective and at first only highlight the most important characteristics of the interface a few major categories of interfaces should be chosen. The category transfer of energy (E) is chosen to visualize how the PIP is correlated to other components in Giraffe AMB (Ericsson & Erixon, 1999). Other characteristics of the interfaces can be used depending on the component/product. The correlation to other components on module level is visualized in the interface matrix, Figure 25. The investigation considered modules that are not present in the power system, although have interfaces to the PIP. The interface matrix shows that the PIP has energy transmitting connections to the power distribution unit, hydraulic unit and geometrical connections to the cabin.

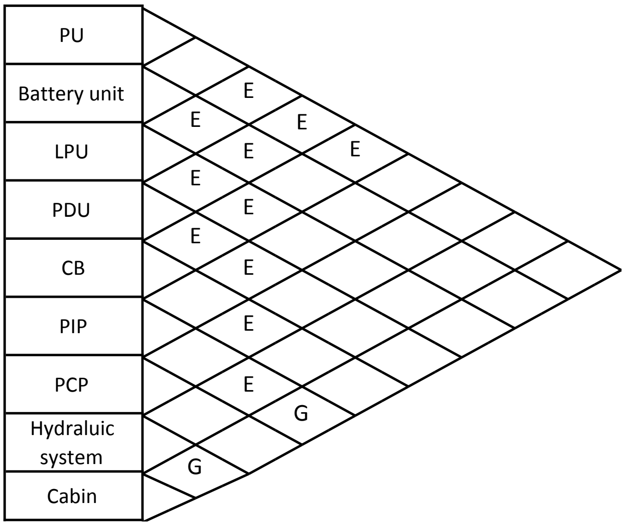

Figure 25 - Interface evaluation matrix for the Giraffe AMB power inlet panel.

5.2.2 Divide the module interfaces into different categories

Different interfaces of the product or system will have different influence on the overall systems; therefore the interfaces need to be categorized. According to Pasche (2007) interfaces can be defined in three categories, A-, B-, and C-interfaces. A Saab EDS specific categorization of interfaces is presented below:

A-class interfaces — Interfaces affecting other main modules or the overall system. A change in these interfaces will lead to structural changes and thus a new modular architecture. A-class interfaces must thus be agreed upon by product management department and in some cases by the executive management people. The interfaces are on high system level for example how the power system is designed to handle the primary radar system.

B-class interfaces — Interfaces affecting less important modules. A change in the interface will lead to changes in other modules but without changes in the modular architecture. B-class interfaces can be changed by Senior Experts from product management or Senior Specialists with an overview perspective of the product architecture.

C-class interfaces — Interfaces affecting modules or components on a low system level. A change in the interface will not change the function of the module and not change the function or interface of any other module. Changes can be made by the product development department for example Senior Specialists from mechanics.

5.2.3 Interface classification

Interfaces were defined, as described by section 4.1.4, with help from wiring diagram and product drawings available for the two systems, Table 6. In collaboration with experienced engineers the classification of interfaces resulted in a division into A-, B-, and C-class as defined in Section 5.2.3 seen in Table 7.

Table 6 - Defined interfaces

Attachment	Transfer		Control & communication	Spatial	Environmental
	Input	Output			
Geometric interface shelter (SDG10214/).	X3 Mains Inlet	X7 230V 50 Hz	X13/14 PDU1/CB1	Geometry limitation of 1273, 518 mm to cabin	Z0: Outdoors area, no EMC-actions
Limited upwards, hydraulic system (KFU901047/).	X4 Ion Pump 230V 50 Hz	X11 LCU			
	X15 28VDC Inlet, Hydraulics Emergency	X12 MAS			
	W19 Power Plant	W88 PDU2			
	W13 Power Plant	W12 Ion Pump			
		W82 LCU			
		W11 PDU1			
		W523 DC Motor Hydraulic System			
		W80 Hydraulic Pump			

Table 7 - Interface classification

A-class	B-class	C-class
Geometric interfaces	W88 PDU2	X13/14 PDU1/CB1
W19 Power Plant	W11 PDU1	
W13	W523 DC Motor Hydraulic System	
X3 Mains inlet	X7 230V 50 Hz	
Z0: Outdoor area, no EMC-actions	W80 Hydraulic Pump	
	W82 LCU	
	X4 Ion Pump 230V 50 Hz	
	X12 MAS	
	X11 LCU	
	X15 28VDC Hydraulics Emergency	

At this stage the module interfaces are defined and the design of the module and its interfaces can begin.

5.3 Organization

To better map the organization with the new modular product architecture, see section 5.1.6, revised organization architecture is developed. The new organization architecture is aimed at supporting the development of uncoupled modules with low demand for time consuming cross module interaction. As the modularization of the product becomes fully developed the next step is to create a modular organization.

The loosely coupled organizational structure and product structure will help Saab with the communication between projects. Currently the integrated product architecture leads to time-consuming activities of communication between projects and departments. The new organization is developed to handle the development of the function within the modules, the interfaces between modules and to structure the communication between modules and from the market. The tools implemented in the organization to solve this are Modular Interface Managers, Module Managers and cross-functional module teams.

The Modular Interface Managers are placed at different hierarchical levels in the organization corresponding to A-, B-, and C-class interfaces see section 5.2. The Modular Interface Managers has a strategic responsible for keeping the interfaces fixed during important time phases. The phases can be important parts of the product development process or for important part of the module life cycle (Sanchez, 1996). Since the Modular Interface Managers has a strategic responsibility they should have continuous communication with the market department. It is important to keep track of the demands from customers in order to have a module structure capable of combining modules creating a suitable product for the customers (Sanchez, 1996). The role as Module Interface Managers will, as an implementation at Saab EDS be a part-time duty for current managers at suitable positions, preferable from product management, OEGP.

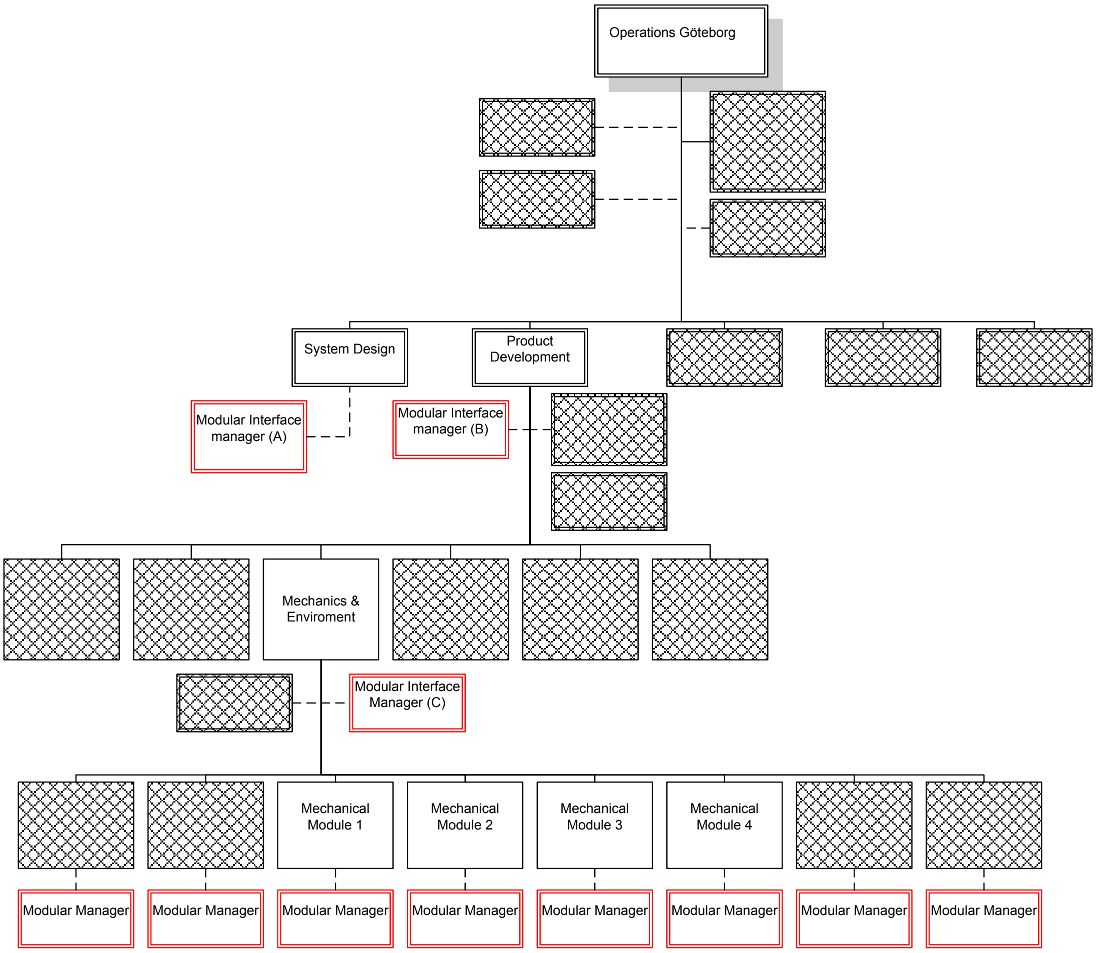

Figure 26 - Saab EDS organization chart included Interface- and Module Managers.

The Module Managers are responsible for the modules within the technical functions. He/she is responsible for having a module that fulfill the interfaces and has a function fulfilling the needs from the market. It is therefore important for the Module Manager to have a continuous communication with people in the market department (Sanchez, 1996). The development activities within the module are performed by a cross functional team of different engineers (Persson, 2011). People currently working as sub-system managers will fill the role as a modular manager. The alterations made to the organization are shown in Figure 26.

The differences between Modular Interface Managers at different hierarchical levels are:

1. The A-class Modular Interface Managers (OEGD(I)) are responsible for keeping an overall perspective of the interfaces between modules. Preferably there can be a separate manager for the systems Arthur and Giraffe AMB. In order to always have a system able to create market leader solutions fulfilling the needs of the customer the communication with the market department is crucial. The position can for instance be filled by managers at Arthur and Giraffe AMB system office (OEGDG). It is the managers' duty to decide during which period of time the interfaces must be fixed. It is the A-class manager who is responsible for making big changes in the architecture and thus responsible for making cost analysis for the changes.

2. The B-class Modular Interface Manager has a stricter product focus. Preferably there can be a separate manager for the systems Arthur and Giraffe AMB. The position implies an overall responsibility of how overall technical solutions are solved between modules. The manager must translate market demands into technical solutions in the modular architecture and create interfaces optimizing the whole system. It is also the managers' responsibility to create efficient communication patterns between modules.

3. The C-class Modular Interface Managers are responsible for the interfaces within his/hers are of technical expertise. The manager must communicate the demands from the market down to the Module Managers and create interfaces allowing a flexible architecture.

All managers independent of A-, B-, or C-class are responsible for communicating changes with ILS, create cost calculation of changes and continuously improve the processes. It is also the managers' responsibility to analyse how changes in the interfaces change the conditions for the module specification. The Modular Interface Manager needs to handle the changes of interfaces during the life of the product. Changes in the interfaces need to be carefully considered. The Modular Interface Manager must revise all documents defining the module when changing an interface.

When implementing modularization both in the systems and in the organization creating new communication and information patterns is important (Brusoni & Prencipe, 2001). New information material and information processes needs to be developed continuously.

5.4 Cost effects and customer adaptations

A modular strategy responds to technical evolutions and allows for customer options in an effective manner (Zhou & Grubbström, 2004), which in the past has been a problem at Saab EDS. Using a modularization strategy, future development activates are allocated to serve in various customer projects. Development activates should in the future be allocated to the module instead of the individual customer. The standardized interfaces enable the module to be backward compatible with the entire product portfolio.

The current situation is proven to allocate a lot of resources for coordination due to the dependencies between sub-systems. The coordination results in costs and extended lead-time. A modular strategy would decouple the product and organization and reduces dependencies, thus reduce cost and lead-time (Baldwin & Clark, 1997). Saab EDS currently needs to store a large number of spare parts and sub-system due to the differential in customer demands. A part or sub-system is stored once for every project. A backward compatible module with the entire product portfolio reduces the need for warehousing

Currently Arthur and Giraffe AMB undergo a mid-cycle upgrade and a modular architecture will facilitate the upgrading process. Equally important, in the military industry is the need for fast maintenance and service. A modular architecture gives opportunities for fast replacement of modules (Brusoni & Prencipe, 2001). At Saab EDS, ILS works as a support functions and develop training, documentation and manuals. A modular architecture would reduce the cost for ILS training, issuing and developing. As already stated modularity is about decoupling functions with standardized interfaces, this could be benefited from in ILS. Documentation can be changed only on the developed module without the need to search and manage changes in the entire system.

5.4.1 Customer adaptations

Defence industry as discussed earlier, is characterized by a high customer power with unique demands. The high customer power is recognized at Saab EDS. Costs are of course connected to time and projects in the past have allocated a lot of cost and time due to customer adaptations made to both Arthur and Giraffe AMB. The adaptation have often spread into the entire system and one of the reason why the projects have allocated so much time is due to the dependencies between subsystems. These changes mean activities to allocate cost in the entire organization.

The current and future situation predicts that the customer demands will require development efforts and reengineering that will cause future changes to the Base Line Product, which are difficult to predict in advance. Changes and costs connected to customer adaptations affect department included in the entire development life cycle. Currently Saab EDS handle customer adaptations by cost estimations and quotations being issued and sent to the customer, presenting the cost of the various adaptations. Project managers from the different departments issue a separate cost estimate. The estimate includes costs derived to sub-systems and costs due to other expenses. Since customer adaptations are difficult to anticipate and be prepared for, this working procedure shows many advantages. However managers must be aware of the extent of the adaptations and how activates correlated to change widespread in the product organization. The Base Line Products are used as a mean to secure carry over between projects and a higher pay off on parts already developed. Since the previous situations demands reengineering on a substantial number of component and sub-systems, often even the entire system.

Currently the cost estimates in different departments are made separately and the connection between product development and production is created rather late in the project. Saab EDS concept of Base Line Product takes this fact into account, as customer adaptations are a part of the Base Line Product, Figure 4.

The cost analysis discusses the economical aspects of modularization derived for literature and how change connected to an interruption of interfaces or design rules effects the cost. The intent is to provide a framework that exemplifies how activities widespread within Saab EDS and drives time and cost when change interrupts interfaces opposed to keeping standardized interfaces.

5.4.2 Change drives activity costs

Activities present in the product development life cycle (Glaumann & Gustavsson, 2002) and by investigating activities correlated to current processes at Saab EDS, Figure 12. The intent is to provide a general framework for decision-making, used to get a feeling regarding the cost of change. Three hypothetical statements can be derived and the cost analysis is built around these.

1. Customer chooses to use modules already developed, hence activities does not allocate cost to the same extent.
2. Customer demands options on modules that do not interfere with the standard interfaces. Hence activities that allocate costs will emerge.
3. Customer demands substantial adaptations on modules that will interrupt standardized interfaces. Activities that allocates cost will emerge and widespread into surrounding modules in the system. Is the customer willing to pay for this?

However, a benefit with modularization is that adaptation and change is allowed as long as it does not interfere with the interfaces. The first two statements above are indented not to jeopardize the standard product and interfaces, hence protect the product and reusability of the product the line has to offer. The third statement, cost due to interface changes will be discussed further in the analysis.

5.4.3 Change scenario

To get a sense regarding the costs of adaptation towards customer requirements a cost estimate was conducted around a scenario were customer demanded changes to the power inlet panel. The change will indefinitely interrupt interfaces and widespread into other parts of the system. The purpose for this scenario is to illustrate how costs are generated and how it is differentiated between the above scenarios.

Following a worldwide economical crisis, which has led to a higher tension within the EU a new customer have shown interest in buying three Giraffe AMB systems. The system should be placed near the border of their historical enemy. Among a list of demands the customer wants a wireless power supply that seems especially challenging.

Recent technology evolutions have made it possible to provide the systems with wireless power from the military base and the customer require that the equipment needs to be integrated in the power inlet panel. With this change the power plant and standard external power inlet could seem useless, however since this is a new technology the customer still feels a need to keep them as backup power supplies.

The customer has requested a quotation from Saab EDS how much this adaptation will cost and how much the change will add to the delivery time. Due to the increasing tension delivery time could be a deal breaker. At Saab EDS the managers are certain that this change is doable. However they realize that this change will cause development effort along with other activities in every department. The adaptation could easily be managed if the change would not affect other parts of the system, but management think that the change will make the power inlet panel bigger and change the geometrical interface. Since Saab EDS recently started a modularization project they are well aware that adaptations leading to interface changes are costly and time consuming.

The new wireless power supply also requires that another set of circuit breakers needs to be implemented. It is though that this will cause the ECP frame to expand vertically by 80 millimetres leading to changes in marriage point interfaces in PIP/ECP and ECP/Cabin. Meaning that the ECP frame but also the cabin needs to be changed to integrate the new PIP in the system. Furthermore the adjacent hydraulic unit needs to be rearranged due to the constricted space; therefore a new packing study on system level needs to be conducted. Other changes that exist as a consequence of the new power supply are neglected.

The above scenario will cause following changes to the system. This information will serve as a background to the cost assessment conducted with personnel from the various departments within Saab EDS. Notable is that the intent is to seek additional costs that lie outside the fixed costs present for the entire system without below changes.

PIP

- Integrate new power supply
- Add a set of circuit breakers
- Internal assembly and cabling
- Separate testing

ECP frame

- Construction update to integrate the new power inlet panel

Hydraulic unit

- New packing study
- Revised cabling
- Integrate

Cabin

- Integrate the updated ECP and the reassembled hydraulic unit

The question now is how much does a change that breaks the design rules cost and if it is true that the change causes iterative activities that allocate costs. The scenario was presented to various departments within Saab EDS with the intent to estimate the cost of breaking the interface.

5.4.4 Cost assessment

Possible costs were assigned to different departments; two kinds of estimates were estimated. First how many working hours could be derived to activities, Figure 12, as a framework, second a direct cost assigned to the department due to for example travels and prototypes. The actual estimation quantified cost packages including sets of the activities that existed in the various departments. The average cost per working used in the calculation has been normalized due to secrecy. The result of the total estimated cost is shown in Table 8.

Table 8 - Cost assessment

	PIP	ECP frame	Cabin	Hydraul unit
Hours	2300	250	550	850
Cost/h	1	1	1	1
Total cost	2300	250	550	850
Additional cost	693	67	467	1067
Sum	**2993**	**317**	**1017**	**1917**

The purpose for the scenario and the cost estimation is to visualize the cost of interrupting interfaces. Costs allocated to the ECP frame, hydraulic unit and cabin are a result of the changed interfaces. The assessment shows how costs widespread in surrounding modules and hence the importance to at all cost keep them standardized. The additional cost in the scenario due to the initial change in the PIP brings an increase in of approximately 100% due required changes in ECP frame, hydraulic unit and cabin. What management needs to be aware of when obliging to customer demands is the cost associated to it. Associated with the three statements made earlier it can be determined that.

1. If the customer chooses to use of the off-the-shelf line modules the cost are of course smaller and will not add to the lead-time.
2. If the interface does not change due to customer standard options the cost is acceptable and the additional lead-time will not increase substantially.
3. If the changes is severe and interrupt the interfaces the cost and the addition to lead-time is substantial.

Perhaps this result was not that surprising and in the next section a framework is suggested to support decision-making when it comes to interfaces and modularization to estimate the cost effects of severe adaptations.

5.4.5 Customer adaptations that changes interfaces

Not obliging to the defined design rules has a substantial consequence on the cost and lead-time, therefore comprehensive product updates need to be carefully implemented (Pasche, 2011). In system like Arthur and Giraffe AMB changes in sub-system affect surrounding sub-system and/or the entire system. This is a recurring fact Saab EDS have dealt with in every customer project historically. The benefit with modularity is as mentioned that it allows for development in sub-systems independently without affecting the system as a whole (Sanchez, 1996). Activities discussed previously, Figure 12, are more or less always existent when developing, adapting or upgrading a component or sub-system. However when interfaces or design rules are interrupted a chain reaction that cause activates to iterate within the different department as changes propagate into other parts of the system, Figure 27. Saab EDS needs to be aware of the magnitude cost is driven by customer adaptations.

Figure 27 – Breaking interfaces will result in activates in the entire development life cycle.

Of course the magnitude of activities correlated to the magnitude of the initial change. To exemplify this statement a scenario where customer adaptation causes an interface to change and is widespread to surrounding modules is discussed. However since the defence industry is a customer market the intent by this suggested framework is not to remove the opportunities for adaptation. The intention is to visualize how cost increases and widespread into surrounding parts of the system when interfaces are interrupted.

6 Discussion

Saab EDS have at the time of writing this thesis recently launched their platform strategy Base Line Product programme. The intent is to offer the market products with short lead-time and low internal cost. This master thesis presents a modularisation strategy that could be used as a complement to the Base Line Products. The following discussion will be separated in the three areas the master thesis has been built around.

6.1 Product

Product modularization is a complex process and the realization is dependent on the skills and expertise of employees. As stated before the procedure of the method is to either integrate parts or sub-systems together into a module or define parts or sub-system that individually form modules.

The functional areas derived for the Base Line Products were included in a first set of MIM on sub-system level. The analysis resulted in integration possibilities on sub-system level, meaning that sub-systems should be merged to form a separate module. However the value in merging sub-systems into modules is questioned at this product level. The result needs to be weighed against technical aspects not included to the extent required for realization. Perhaps sub-systems defined in the currently Base Line Products can be defined as modules and interfaces standardized.

One request from Saab was to investigate opportunities for shared modules between the two systems. The analysis shows that economically benefit of shared modules could be found at component level. If part of the systems is to be shared on higher system level redesign of the architecture need to be done. But big architectural changes is resource demanding. Saab must make a trade-off of the potential future savings of shared parts on higher system level compared to the investment cost making it possible.

The framework for interface management with classification of A-, B-, and C-class interfaces needs to be revised before being implemented. The classification has other aspects that are important to notice, it provides opportunities for a one-to-one mapping with the organization when interface responsibilities are distributed.

The modularization strategy suggested complements the Base Line Products by creating option modules with standardised interfaces. But Saab EDS should strive to extend the modularization degree of the systems to also incorporate modules in the Base Line Products. By having a totally modular architecture it is possible to create customer specific systems with short lead-time and at low cost. By building the whole system out of different modules it is possible to easily create distinct products with high degree of common parts.

6.2 Organization

The revised organization architecture presented in the results is not a one-to-one mapping of the revised modular architecture. The new modular organization should not be perceived as the ideal final solution for the company but as a relevant first step. Provided that the interest for modularization increases and the potential are understood further steps must be taken to better map with the product architecture.

There is no change in the number of hierarchical levels in the revised organization architecture compared to the current one. But with new communication patterns from the market department to the Module Managers and with defined interfaces the need for coordination should decrease.

When implementing changes in the organization the cost correlated to the changes is important. The new positions introduced are Module Managers. There are seven new Modules for Arthur and nine for Giraffe AMB. Relatively seen compared to the whole company is it an increase of about 1% collaborators. A well functioning modular architecture will cut development lead-times and thus cost by far more than the expenses of new staff making it a profitable solution from an organization perspective.

6.3 Cost and customer adaptations

The report has argued with literature as a background that modularization has cost and lead-time effects in the entire lifecycle. Much of the benefits are correlated to the functional decomposition with well-defined standardized interfaces. According to the module drivers presented in section 5.1.2. The base line program includes carryover since it functions as a platform. But from a cost perspective it is vital to functionally uncouple modules using standardised interfaces. A major challenge in Saab EDS base line programme is to preserve the standardized interfaces over time. By securing the interfaces over time options and continuous development in modules can be performed with a lower total cost.

The product part of the master thesis has incorporated the module and option of the Base Line Products. Customer adaptations are difficult to consider in the modularization context since these often are unknown to Saab EDS, there it is difficult to address or create standardized interfaces to unknown “modules”. In this master thesis a framework or set of mind is presented and exemplified around three types of customer projects. The framework presented is general but intended to raise the awareness of cost connected to changes and customer adaptations interrupting the standardized interfaces. The framework also assumes the standard customer options to be defined as modules with a system that can integrate these without affecting the system as whole. The company currently has cost estimation meetings which should be continued but with a clearer modularization focus.

Initially the company mainly focused on the product perspective of modularisation and especially on geometrical factors. But it is essential to understand that products cannot be modularized without changing the organization and understanding the costs associated with an integrated product architecture. Top management within the company must understand that the upfront cost of implementing modularization is big but the potential savings are greater.

7 Conclusion

The purpose of this thesis is to establish a modularization method for Saab and to illuminate product-, organizational-, and cost aspects correlated to modularization. The conclusions will compound the results and analysis of the three areas.

From the analysis and results it is concluded that Saab EDS is ready to implement a modularization strategy. The market has clearly changed and the company itself has started the work creating a platform strategy, the Base Line Product programme. Modularization clearly complements the Base Line Products and is thus considered meaningful. To be successful with the implementation of modularization it is important to move it to the same hierarchical level in the organization as the base line programme. At the technical department the work currently is performed at only the product part of modularization is considered resulting in problems utilizing the full potential of the method.

One of the main demands of the modularization strategy was to show that it reduces lead-time and development costs. It can be concluded with support from literature that the new method will reduce lead-time mainly from less communication activities and from concurrent engineering. The results from the cost analysis highlight the cost for breaking interfaces and making it easier to correlate costs to customer requirements. By having well defined interfaces and knowledge about the cost of breaking them it will be easier to price big changes to the customers.

The thesis presents a new modularization method for Saab EDS. The method is built on the most relevant and recent literature with lesions learnt from other industry leading companies as benchmark. The method for the product can briefly be summarized as:

1. Select technical solutions at a certain system level.
2. Identify possible modules using a Module Indication Matrix.
3. Analyse, standardize and classify the interfaces.

Combined with the new positions Module Managers and Modular Interface Managers responsible for the content and interfaces of the modules over time Saab has a good framework for modularization. Utilizing a modularization and platform strategy it will be possible to create distinctive systems and at the same time using a high degree of common products.

Saab Group is a global actor with development offices all over the globe. Creating an uncoupled modules with well-defined interfaces make it much easier to perform development activities of the same system at geographically disperse areas. It will be easier utilizing expertise within the whole Saab group with little need for managerial coordination.

The final conclusion of the master thesis is that Saab EDS should continue with the Base Line Product programme to build a platform for the future. But it is essential to combine it with a modularization strategy. When implementing platform and modularization strategies for new products are important to be caution and analyze the product. Modularization as a method is not suitable for all products and must be individually reviewed. If a product is totally financed by an external sponsor like FMV the upfront investment for modularization must be compared against the option of creating an integrated product.

8 Recommendations

The thesis has scanned big parts of the available literature and created a framework for a modularization method at Saab EDS. In order to implement modularization as a development activity the method needs to be easily accessible for everyone interested. In order to make the hands-on parts of the thesis easy accessible, a summation of the method in the form of an A3 is made. A schematic presentation of the method can be seen in Figure 28 and the full A3 is presented in Appendix 5.

<table>
<tr><td colspan="2">Product modules

Description of how to define modules included in the Base Line Product and standard options using Modular Indication Matrix. Common modules between the two products should be pursued at component level.

Description of how to define and classify standardized product interfaces between modules according to A-, B-, and C-class depending on their importance.</td></tr>
<tr><td>Cost and customer adaptations

Be aware of cost of breaking interfaces and customer adaptation. Benefits with modularization are connected to standardized interfaces. Changes leading to substantial interfaces changes needs to be carefully implemented.</td><td>Organization

Assign managerial responsibility for the interfaces and function of the modules on different levels in the organization, with a one-to-one mapping with the product.</td></tr>
</table>

Figure 28 –Schematic presentation of the A3.

A3 as a report form is currently used at Saab EDS and according to Liker & Morgan (2006) facilitate knowledge management and archiving of knowledge in a structured way. The A3 should be used in development processes and be easily accessible in the PDM system. It can also be used in group discussions regarding modularization on both managerial as well as engineering level.

It is important to adapt the developed method to the needs of the engineers working with the development of a modular architecture. The modularization method needs to be adapted to both company- and product specific information. Examples are; how long time interfaces of modules must be fixed and which interfaces are classified as A-, B-, and C-class interfaces. It is important to see the thesis as a first step to guide Saab EDS in the right direction towards modularity but the work of creating new processes for modularization must be continuous activity.

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Appendix 1

Interviewees

Peter Bung

Peter Engström

Jan Rydén

Martin Nyman

Tommy Olsson

Tomas Sjöberg

Matti Skogenstrand

Pierre Sandgren

Jan-Olov Winnberg

Leif Söderström

Cost assessment meeting

Kenneth Eriksson

Pierre Sandgren

Glenn Eriksson

Jonas Svensson

Linda Hamlet

Base Line Product meeting

Christer Bjurek

Pia Falk

Jan Ehlersson

Jan Rydén

Christian Sandberg

Terje Erstad

Peter Svedhem

Stefan Brunzell

Thomas Green

Staffan Lennartsson

Michael Ryd

Jonas Ottosson

Appendix 2

Carryover

Strong (9 points):	System of the new Mod C base structure that can be entirely carried over from one customer project to the next. The system has no reasons of being changed during the lifetime of the current Mod C platform.
Medium (3 points):	System of the new Mod C base structure that can be entirely carried over but might be changed during the lifetime of the current Mod C platform.
Weak (1 point):	There are strong reasons that the system will be changed during the lifetime of the current Mod C platform and only parts can be carried over.

Technology push

Strong (9 points):	There is strong evidence that the entire system will be changed due to technology evolution or changed demands from the customer during the lifetime of the Mod C platform.
Medium (3 points):	There are strong reasons that parts of the system will be changed during the lifetime of the Mod C platform.
Weak (1 point):	There are only hypothetical reasons of changes due to technology evolution or customer demands.

Product plan

Strong (9 points):	There are documented plans, with referable released document status, of changes in the system or parts of the system.
Medium (3 points):	There are unofficial statements that changes will be made to the system.
Weak (1 point):	There are no official or unofficial statements of changes but changes in other parts of the platform require will require change.

Different specification

Strong (9 points):	Systems in the product that create variation for the customer. Only include systems that are designed to handle variation, exceptional customer cases are not included.
Medium (3 points):	Parts in the system that create variation for the customer.
Weak (1 point):	Parts that due to bad design is correlated to parts creating variance and is hence need to be changed.

Styling

Strong (9 points):	Systems that strongly contribute to the brand design image of Saab.
Medium (3 points):	Parts of the system that contribute to the brand design image of Saab.
Weak (1 point):	Parts or systems that partly contribute to the brand design image of Saab.

Common unit

Strong (9 points):	Systems that carry the same function in both the ground based Arthur and Giraffe AMB and therefore can be shared across the platforms without design changes.
Medium (3 points):	Parts of a system is the same in both Arthur and Giraffe AMB and can therefore be shared without design changes.
Weak (1 point):	There are parts doing the same function but the systems or parts need to be redesigned and shared across the platforms.

Process and organization

Strong (9 points):	Produced using predefined processes in-house.
Medium (3 points):	Produced out-sourced using predefined processes.
Weak (1 point):	Produced using out-sourcing only stating the function not the process.

Separate testing

Strong (9 points):	Testing of all function of the system can be done separately before final assembly.
Medium (3 points):	Testing of most functions of the system of parts of the systems can be done before final assembly.
Weak (1 point):	The system or part is functionally coupled and can therefore only be partly tested before final assembly.

Supplier availability

Strong (9 points):	The system can be purchased as a module directly from a subcontractor.
Medium (3 points):	Functionally uncoupled parts of the system can be purchased from different subcontractors and assembled to a system.
Weak (1 point):	Only parts of the system are purchased from subcontractors.

Maintenance and service

Strong (9 points):	Critical values between 1-20 in the Failure Mode Effect Analysis, FMEA (IFS: 1594/).
Medium (3 points):	Critical values between 21-80 in the Failure Mode Effect Analysis, FMEA (IFS: 1594/).
Weak (1 point):	Critical values between 81- in the Failure Mode Effect Analysis, FMEA (IFS: 1594/).

Upgrading

Strong (9 points):	Systems that regularly needs to be upgraded.
Medium (3 points):	There are parts in the system that regularly needs to be upgraded.
Weak (1 point):	Parts in the system that occasionally needs to be upgraded.

Appendix 3

PIP AMB		
Component	**Item number**	**Number**
Circut breaker	CLASSIFIED	2
Switch		1
Switch		1
Switch		1
Emergency switch		1
Power plug		1
Power plug		1
Frame		1
Sheat metall		1
Fixed sleeve connect		1
Fixed sleeve connect		1
Voltage relay		1
Holder		1
Holder		1
Bolt		1
Contactor		1
Contactor		1
Contactor		1
Relay		1
Filter		1
Filter		2
Illumination		3

PIP Arthur		
Component	**Item number**	**Number**
Circut breaker	CLASSIFIED	2
Switch		1
Switch		1
Emergency switch		1
Power plug		1
Power plug		1
Frame		1
Fixed sleeve connect		1
Voltage relay		1
Bolt		1
Contactor		1
Relay		2
Filter		1
Illumination		1
EMP protector		1
Gable		1

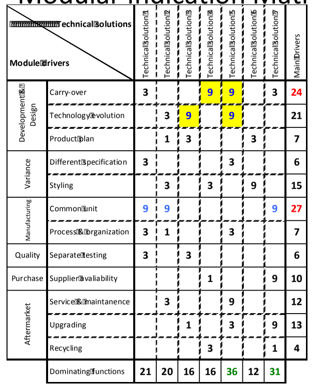
Appendix 4

Understanding the Modular Indication Matrix and the Modular Drivers

To be able to take decisions regarding modularization considering all functions within the company different Module Drivers are used.

Module Driver; Carry-over, Technology Push, Product Plan

Modular Indication Matrix



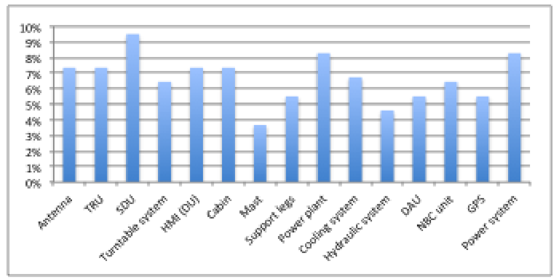
More information see, section 4.1.3.

Select technical solutions at a certain system level at atime.

Select system level for modularization:

System level, Sub-system level, Module level, Componentlevel

Asses functional areas with strong reasons for modularization using a Modular Indication Matrix.

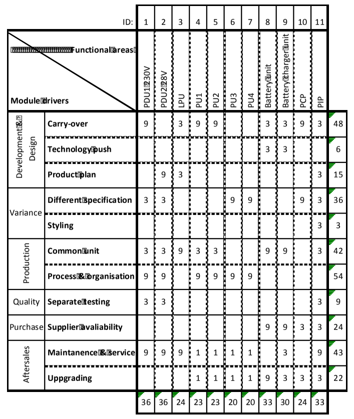


More information see, section 5.1.1.

Identify possbile modules

- Module drivers
- MIM
- Integration

Perform a MIM analysis in a cross-functional group assessing the Module Drivers in the Modular Indication Matrix. Resulting in which parts are suitable for creating a module and which parts can be integrated.

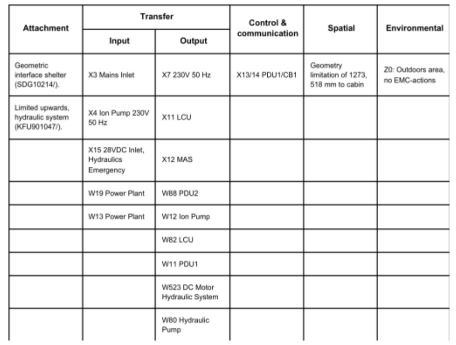


More information see, section 5.1.3-5.1.6.

Analyze interfaces

- Selection matrix
- Interface matrix
- Evaluation

Establish the interfaces between different modules using a Interface Matrix.



Classify the importance of the interface according to:

A-class interface	Difficult to change
B-class interface	Depends on situation

More information see, section 5.2.

Modular Architecture

Product

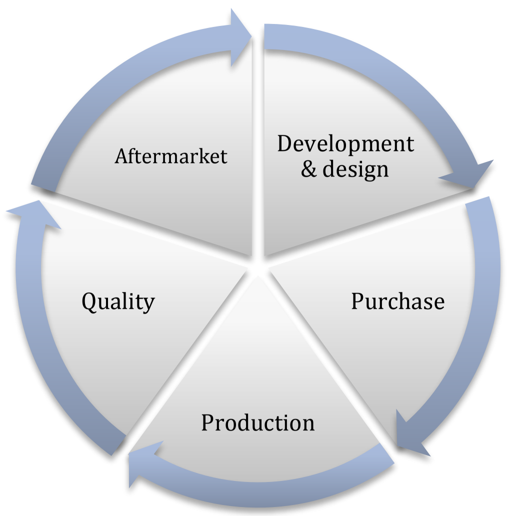
Cost Aspects

Organization

Cost calculation can serve as decision making facts when deciding to modularize a part or a whole system.

The cost estimation should be performed by a cross-functional group.

For an example of the cost of breaking a interface see section 5.5.2.1.

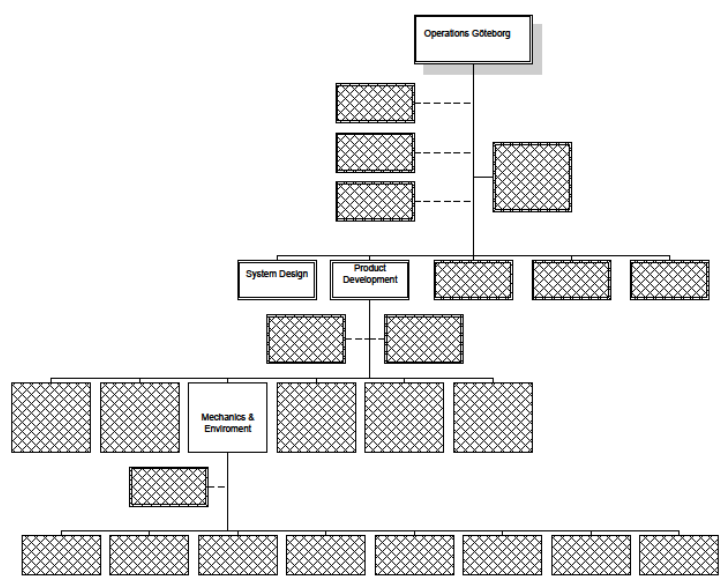


More information see, section 5.4.

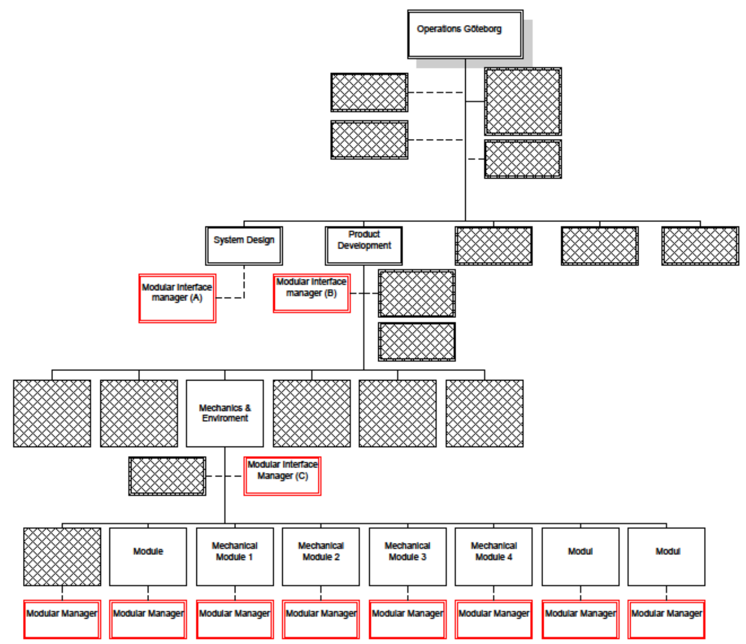
Changes made as a first step

- Modular Managers at different hierarchical level corresponding to A-, B- and C-slass interfaces
- Module groups within the Product Development function
- Better communication between market and product development

Current organization



Modular organization



More information see, section 5.3.