# The Next Generation's Power Distribution System

## Development of a system-level concept for Saab Surveillance

A Master's Thesis in the Master's Programme Product Development

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# Abstract

This Master's Thesis covers the concept development of Saab Surveillance's next-generation Power Distribution System (PDS) for naval application radars. The aim was to design a new concept while focusing on lowering the production cost. This was enabled by a current-state analysis where a comparison in terms of function and cost was made of Saab's two PDS designs: the Integrated PDS and the Modular PDS. This led to the thesis focusing on the mechanical design of the PDS as the total costs for chassis and mechanical parts were found to be higher than expected.

To further understand the needs of different stakeholders, seven interviews were held with eight Saab employees with varying roles. Due to confidentiality reasons, customers and end-users were unfortunately not possible to contact. Each customer requires a high degree of customization, which is one of the greatest challenges for the development effort, along with the production volume being very low. This led up to a concept generation phase which was preceded by benchmarking, a shorter literature study, and brainstorming. The concept generation resulted in five system-level concepts on a scale from a modular to an integrated product architecture. After a screening process, the concept named *Bravo* was chosen to develop further.

The final *Bravo* concept is a system-level concept of a new mechanical design that re-uses the already military rugged and verified outer chassis of the Modular PDS. A unit within the chassis is also greatly inspired by the larger internal unit of the Integrated PDS, which has a low production cost and eases production and service of the PDS. To increase flexibility and lower development costs in each new project, *Bravo* includes Consumer-Off-The-Shelf (COTS) Power Distribution Units (PDUs). These COTS units are a crucial aspect for the design to keep development costs of the PDS low. However, there were limitations to identifying the exact units to apply, which is a further development recommendation for Saab to investigate. The system-level concept became a hybrid of modularity and integration to best handle the diverse requirements of future projects while keeping development and production costs low.

Keywords: Power Distribution System, PDS, Product Development, Radar System, 19-inch, COTS

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# List of Abbreviations

| | |
|---|---|
| COTS | Consumer-Off-The-Shelf [products] |
| DC | Development Cost |
| ECI | Electrical Connection Interface |
| HMI | Human Machine Interface |
| MFG | Mains Failure Guard |
| MOTS | Modified-Off-The-Shelf [products] |
| PC | Production Cost |
| PCP | Power Control Panel |
| PDS | Power Distribution System |
| PDU | Power Distribution Unit |
| PSI | Power Signal Interface |
| SOL | Switch-On-Logic |
| TRAF | Transformer |

# Contents

# 1 Introduction

The *Introduction* includes a *Background* of Saab, Saab Surveillance, and the product to be re-designed: a Power Distribution System (PDS). The *Aim* of the thesis and the *Scope* are formulated to guide the development work. Furthermore, the *Process* of how to reach the *Aim* is stated. Lastly, the *Stakeholders* of the thesis project are listed to give an early understanding of who the deliverables of the thesis are valuable to.

## 1.1 Background

The company Saab and the affiliate Saab Surveillance are presented to gain an overview of the company and the products they offer. The product to be re-designed, the Power Distribution System, is also introduced. Lastly, the problem description is formulated.

### 1.1.1 Saab

Saab provides world-leading solutions, services, and products from military defense to civil security to the global market of governments, authorities, and corporations. Their vision is that it is a human right to feel safe and that their security systems make this a possibility (Saab, 2019a). Saab Surveillance, hereon referred to as Saab, develop and produce security and safety solutions for surveillance, decision support, threat detection, location, and protection. Their product portfolio includes ground-based, airborne and naval radars, combat systems, electronic warfare and C4I solutions (Saab, 2019b).

Saab completes a project, from confirmed order to delivery of a radar system, on average for six years and develops approximately 2-3 projects simultaneously. The production volume of their products is low due to each project's level of complexity, uniqueness and high level of technology. The market for security and safety solutions is relatively stable in regards to recessions which enables Saab to have a fairly even occupancy.

### 1.1.2 The Power Distribution System

Saab's radar solutions come with a Power Distribution System (PDS), which main function is to distribute various voltage sources, depending on its application and customer requirements. Within the PDS there are many components with different purposes. They collectively take in, monitor and regulate the different voltages and distributes them to various units of the radar system. The PDS acts as a 'base product' offered along with the radar system, where Saab has had two different designs: an integrated and a modular design, hereon referred to as the Integrated PDS and the Modular PDS. See Figure 1.1 and 1.2 for a view of the chassis.

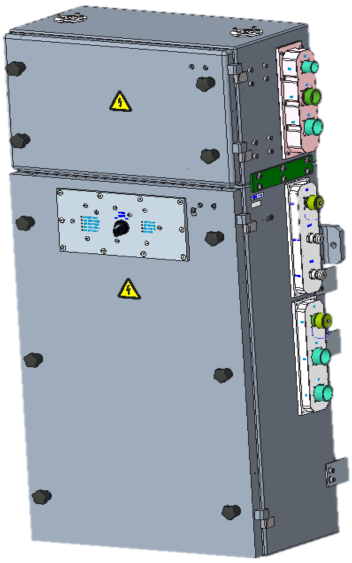

**Figure 1.1:** ISO view of the Integrated PDS.

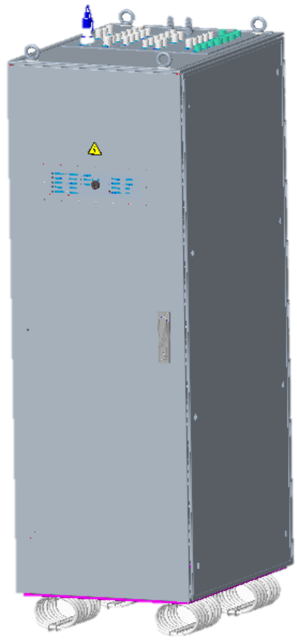

**Figure 1.2:** ISO view including description of functions' order of the Modular PDS.

#### The Integrated PDS

The older PDS design has an integrated layout, where all the functions are incorporated into two chassis, a top and a bottom. Due to a technological advancement which required more space, the Integrated PDS was modified by adding a top chassis on top of the old, bottom chassis. A later project then needed further modification due to a required capacity increase. The Integrated PDS was too rigid in its design to scale up to fit the additional components. The Integrated PDS is, however, still in production due to it's low production cost.

**The Modular PDS**

The Modular PDS has a newer construction method. It's chassis contains separate units which are standard sized 19-inch metal chassis, purchased as Consumer-Off-The-Shelves (COTS) products from a supplier. The units are modified by Saab and are later placed on top of each other and mounted in a standardized rack. The 19-inch chassis is a product applied in other markets, e.g. within telecom, and is utilized in other similar products within Saab's product portfolio. The dimensions of the 19-inch units are standardized to only vary in height in the scale of U, where 1U is equal to 44,45 mm.

### 1.1.3 Problem Description

Development of the Modular PDS aimed at achieving modularity, sought to lead to lowered production costs in future projects. The first Modular PDS was supposed to carry most of the development cost for coming projects. This was however not the case as each project differs in customer needs and requirements which affect the design. Because of the varying needs and requirements per project, there are just as many variants of the different units as there are projects. The units are hence customized per project and are, therefore, not modular. The production cost of the Modular PDS was much higher than expected and did not posses the desired modular qualities. For these reasons it was only produced the one time it was developed.

The crucial functions of the PDS lay within power and electronics, although it is believed to be the mechanical parts of the product that stand for a significant amount of its total cost. Saab has not assessed the costs in detail but more of an overview. Saab has identified the PDS's mechanical improvement potential, as neither the Integrated nor the Modualar PDS fulfill their requirements. Saab is therefore aiming for a next-generation design for the future PDS that better adapts to the varying customer requirements while keeping costs low.

## 1.2 Aim

The aim of the thesis is to compare the Integrated PDS with the Modular PDS in terms of functionality and cost to develop a new mechanical design of the PDS for future projects. The purpose is to compare the two PDSs functions and identify which functions in their respective design are the main cost-drivers. This analysis will then act as the base for a mechanical re-design of the system, taking into account the different users needs and requirements based on interviews. The aim is hence to:

*Design a new concept for the next-generation PDS which facilitates customization, while focusing on lowering the production cost.*

## 1.3 Scope

This project is the coarse of a Master's Thesis carried out by two students at Chalmers University of Technology with a BSc in Mechanical Engineering and MSc in Product Development. The thesis was performed at full time during the spring of 2020.

The analyzed PDSs are two similar systems of different generations, used in Saab's naval radars. Saab produces PDSs of the same function used in ground-based and air-born radars as well, although with different environmental requirements and customers where each have different needs. Limiting to one application area, i.e. naval, will enable a more thorough analysis. Furthermore, as no project requirements are alike, the base-product offering is the object of analysis and re-design. The result will be a re-design of the hardware surrounding the electrical system, that carries and protects it from it's environment.

For confidentiality reasons, some restrictions had to be set regarding displaying numbers such as costs, as it could be harmful to Saab's market position. The cost aspects that will be taken into account are the production costs of the PDSs. As the development costs, such as designing the systems, are embedded within the project, are they harder to analyze. Because of confidentiality reasons customers were not possible to contact and hence first-hand information on use-situations can not be explained. This also entails that the input on customer needs and requirements will have to be retrieved through Saab employees who themselves have direct or indirect customer contact. However, as the hardware within the system is not confidential, nor is the information on internal handling and user interaction, this should not hinder the development effort.

## 1.4 Process

The chosen development process for the thesis is greatly influenced by the methodology provided by Ulrich and Eppinger (2012). In Figure 1.3, their process has been adjusted to better fit this thesis project.

The product development process in Figure 1.3 seems visually as a stage-gate, waterfall-type process but is iterative to a great extent. E.g., naturally, a customer needs study has to be performed prior to stating the needs and requirements for the concept and prior to starting off any concept generation activities. However, some internal and external information searches, brainstorming and benchmarking activities have to be performed along with concept generation and perhaps iterated as one learns.

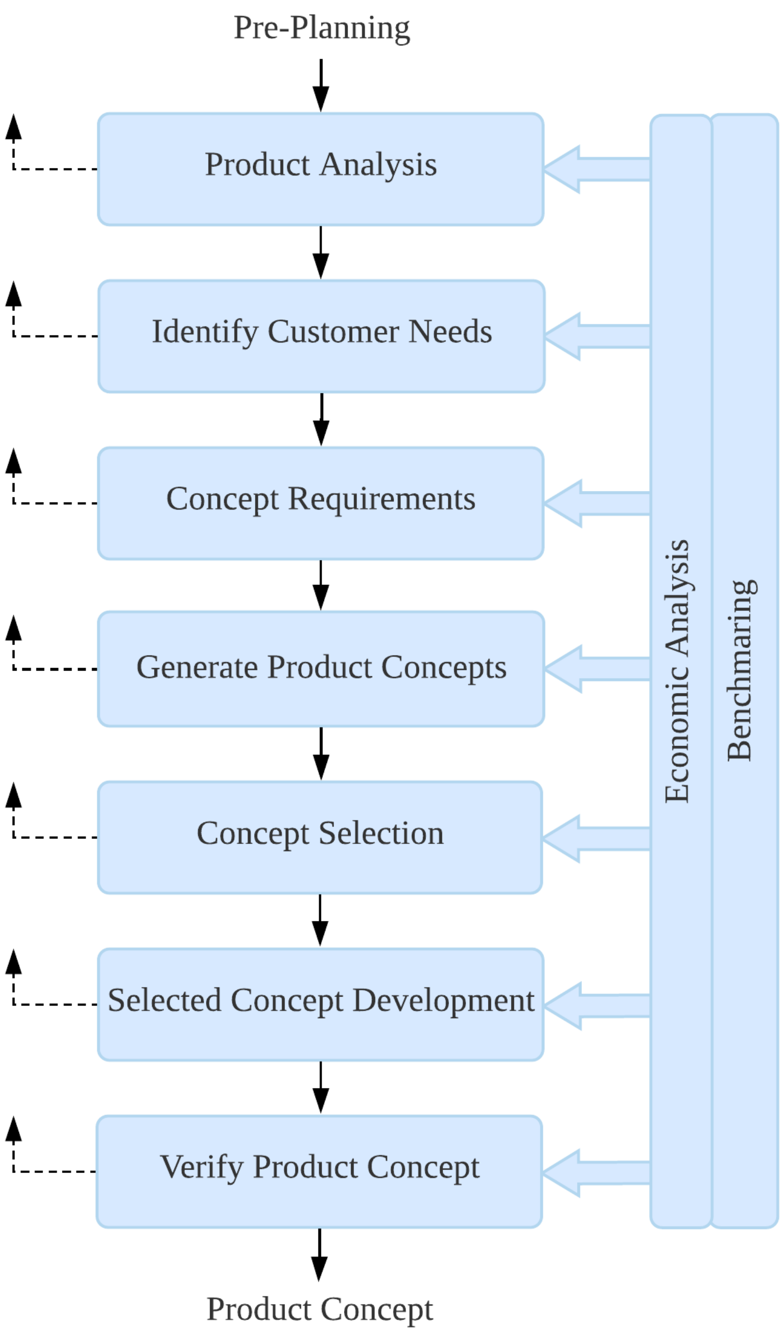


**Figure 1.3:** The product development process, inspired by Ulrich and Eppinger (2012).

As Figure 1.3 shows, a continuous economic analysis will have to be performed in parallel to the development work, throughout the process. The economic aspect is a central requirement of the project on Saab's account and hence should be a central concern during the development work. As the PDS is a complex, non-consumer product, the need for continuous benchmarking is required to contextualize its use and for inspirational purposes during concept development.

## 1.5 Stakeholders

This thesis contains three archetypes of stakeholders. The first:

- Saab Surveillance, receiving a less expensive solution which is better suited for their production, and customer and user needs. An improved product could yield a better market position, which in turn could increase profit, leading to greater resources to spend on projects.

The second:

- Customers and users of the next-generation PDS, who receives a product which better fits their needs and requirements.

The third:

- Chalmers University of Technology, who gains a closer industry contact with Saab Surveillance, and a better understanding of how mechanical engineers can be a part of developing power and electronics products.

# 2

# Product Analysis

*Product Analysis* contains and explains the activities important for gaining a greater understanding of the Integrated and Modular PDSs, and the different challenges that they each bring about. First off, a *Product Description* of each PDS was included to introduce their structure and increase comprehension before making the analysis'. To make a fair comparison of the two PDSs, a mapping of their functions was done in a *Functions Analysis.* An *Economic Analysis* was further performed to pin-point which the main cost drivers were of each PDS.

## 2.1 Product Description

A more detailed description of the two PDSs is presented in the following section. It contains images and explanations of the different products and units, to gain an understanding of how each PDS is structured.

### 2.1.1 The Integrated PDS

The PDS of the integrated design is referred to as the Integrated PDS. The functions are separated into two units, the top unit being the Power Signal Interface (PSI) and the bottom unit the Power Distribution Unit (PDU), see Figure 2.1.a. The PSI and PDU are assembled separately and later assembled together by screw joints. Cabling between the units solely runs on the outside of the chassis. Each unit has cable contacts with inlets and outlets on both sides of the PDS. The assembled PDS is provided with dampers at the bottom and back of the chassis to absorb shock and vibrations (not shown in the figures as they are not included in the CAD model). At the top of the PSI are metal rings which enable lifting the PDS, e.g. during installation. On the door of the bottom chassis is a Power Control Panel (PCP) which communicates with the user by positive and negative diodes. The PCP also includes the main power switch which turns the PDS on, off or puts it in remote to be controlled from a distant control panel.

Each unit opens by loosening the knobs on the front chassis doors and turning them open with hinges, which gives the view shown in Figure 2.1.b. In this state, the fuses and switches are made accessible to the user. The electronic components are protected by a metal housing, both for the users safety and to avoid involuntary contact with the inside of the PDS. The housing is removable by loosening six screws and then lifting the cowl off by using the handles displayed in Figure 2.1.b.

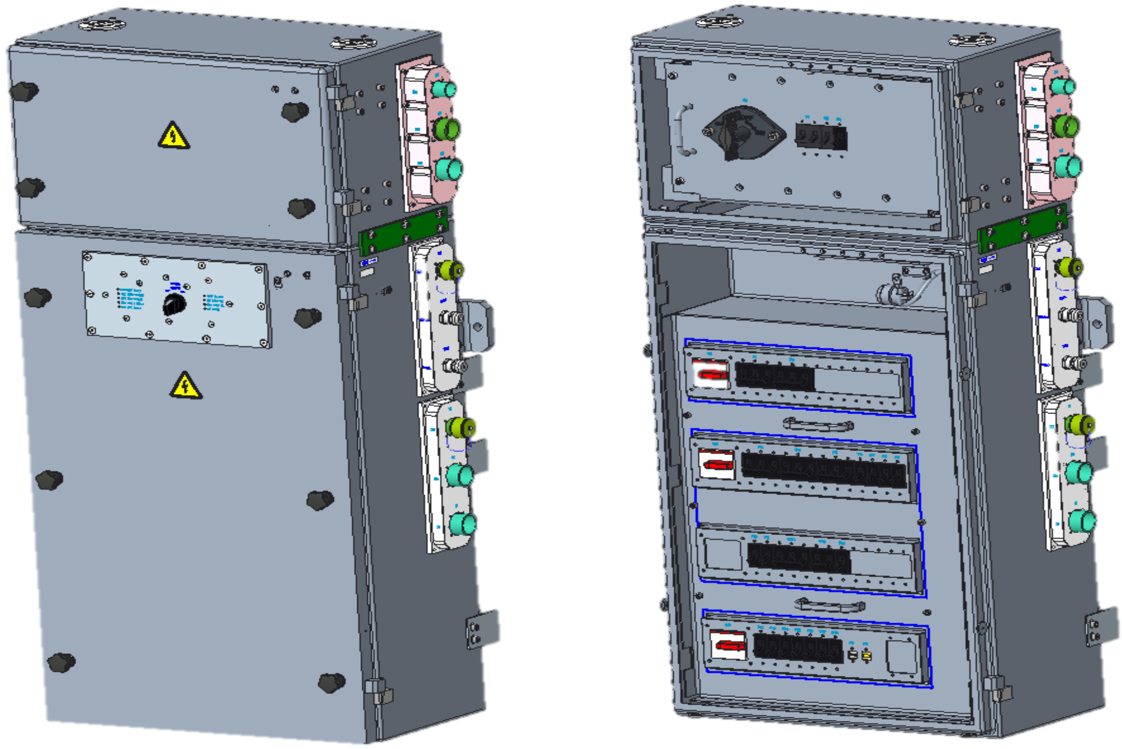

**Figure 2.1:** Integrated PDS, closed front (a) and semi-open front (b) view.

When the safety-cowl is removed, the PDS looks as in Figure 2.2.a. The bottom chassis, the PDU, is structured in two vertical layers. The front layer is a metal plate where all fuses, switches and their cabling are placed. The front layer is opened up by hinges, as shown in Figure 2.2.b. By the hinges side, the cabling from the fuses and switches are pulled to the back layer. The back layer is a metal plate that is fastened to the back of the chassis, where all the components are placed in a shared space.

The top unit, the PSI, is smaller than the PDU but has the same structure of the two layers, where the front contains all the switches and fuses and the back its components. Due to its size, a hinge solution is not required. The front plate is instead unscrewed and lifted off. As previously mentioned, the internal components of the PSI can not be shown. Although, to visualize how much of the space is utilized in the PSI, the components on the plate were kept to display that it is the internal cabling that limits the size of the unit.

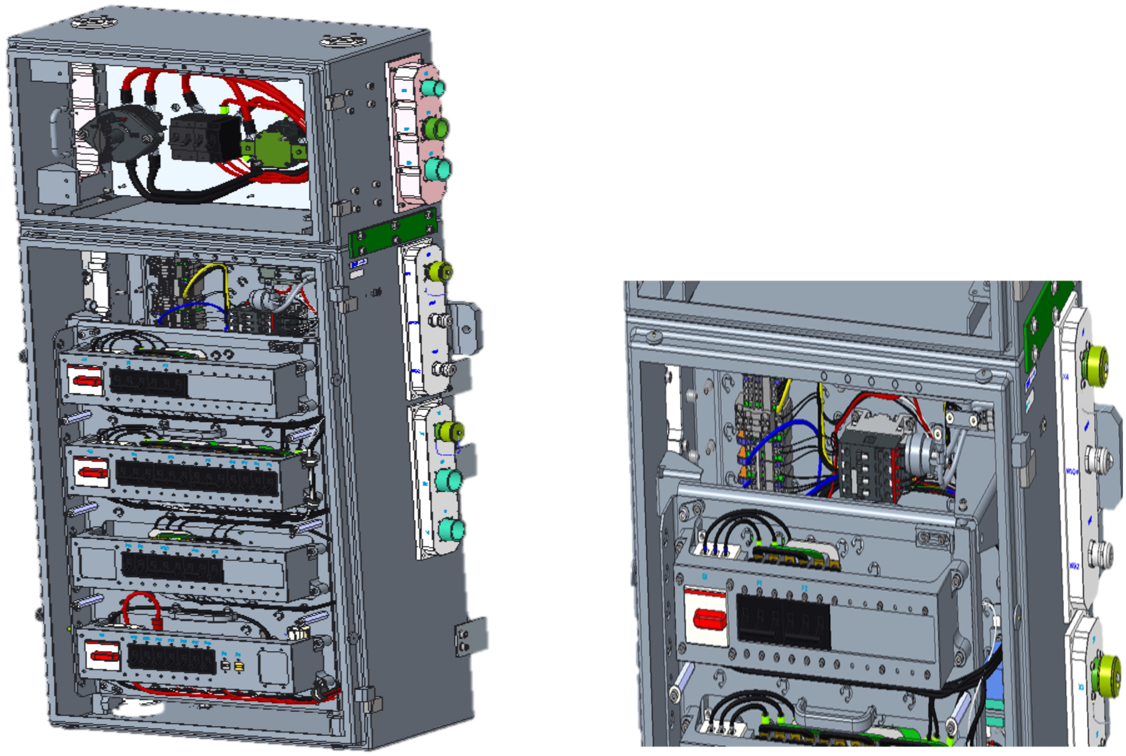

**Figure 2.2:** Integrated PDS, open front (a) and open front close-up (b) view.

### 2.1.2 The Modular PDS

The Modular PDS has a standardized 19-inch chassis with in- and outlet cable bushings and contacts placed at the top. Same as for the Integrated PDS, there are dampers at the bottom and back of the chassis for shock absorbing. Likewise, the chassis is provided with metal rings at the top to enable lifting the PDS. A PCP is placed on the front door which communicates with the user through positive and negative diodes, and has a main power switch. See Figure 2.3.a for the view of the outer chassis.

The front door opens by turning the handle and swinging the hinge-mounted door open. Figure 2.3.b shows the view of the PDS with the front door opened, exposing the different units of the PDS. The included units are standardized 19-inch metal units placed within a 19-inch rack. Alterations had to be made to the design of the rack and units to be able to carry the assembled units' weights. Such adjustments included additional beams, fixtures and dampers to ensure fulfilling the environmental and mechanical requirements of the PDS. The outer chassis was also reinforced to increase robustness.

The units within the Modular PDS are individually modified, assembled, and placed within the rack of the large chassis. Each 19-inch unit has its respective fuses and switches placed on the front. On the back of the units there are cable bushings and/or, contacts depending on its application. All cables between the units are drawn in the space between the back of the large chassis and the backs of the units.

As the back of the large chassis is closed, the PDUs have been provided with rail mounting to enable them to be pulled out, see Figure 2.4. Therefore, the units with rail mounting have also been provided with a cable arm at the back of the units, so that the cables can follow the motion of the units when pulled out.

In Figures 2.4-2.5, two of the units are presented to visualize the utilizing of the space. Figure 2.4 display the unit named 'PDU3' and Figure 2.5 display the unit named 'PDU1'. The fuses, switches and cables are the limiting factor of the units heights, and not the electrical components which they contain. In PDU3, the limiting factor is the amount of fuses and in PDU1 it is the cabling. In some other designs of PDUs it can also be the amount of cable bushings or cable contacts that requires a certain height. The height of a unit is standard U, where 1U equals 44,45 mm. PDU3 is 4U high and the PDU1 is 2U high.

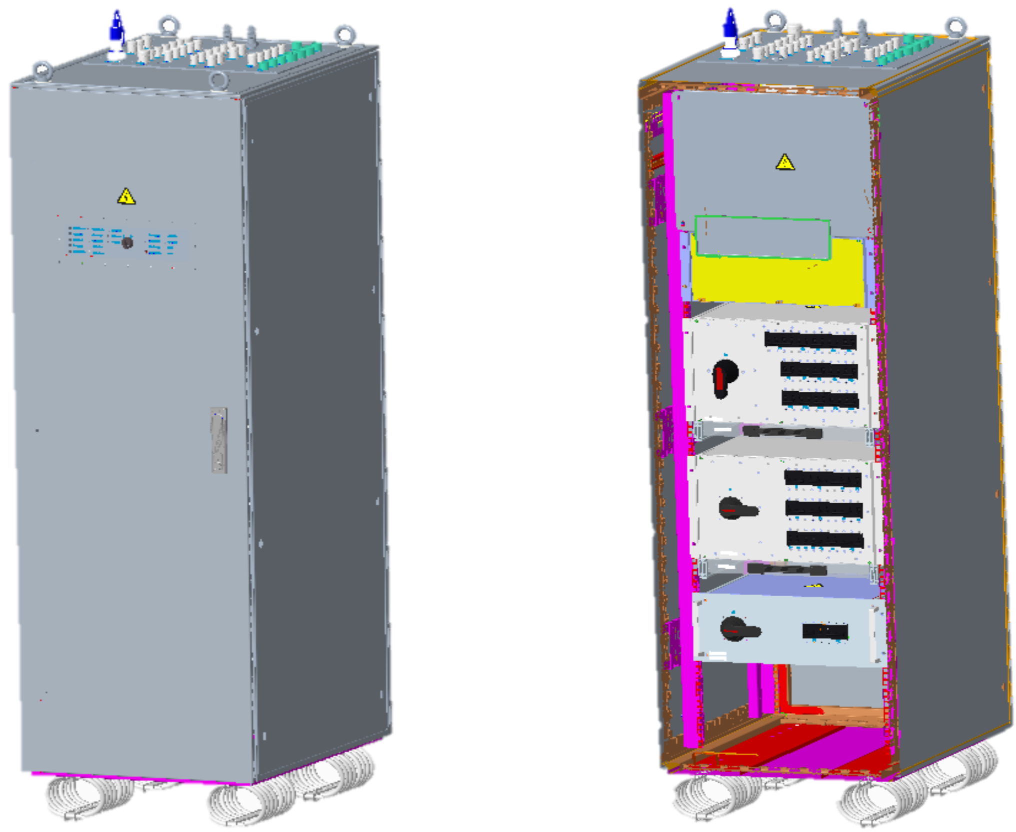

**Figure 2.3:** Modular PDS, closed front (a) and open front (b) view.

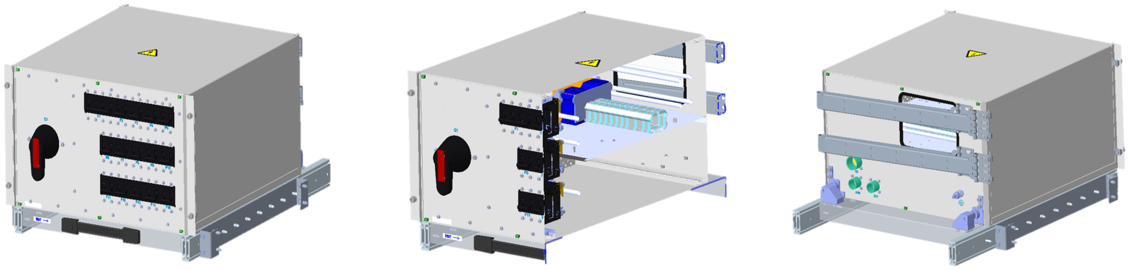

**Figure 2.4:** PDU3, front (a), open front (b) and back (c) view.

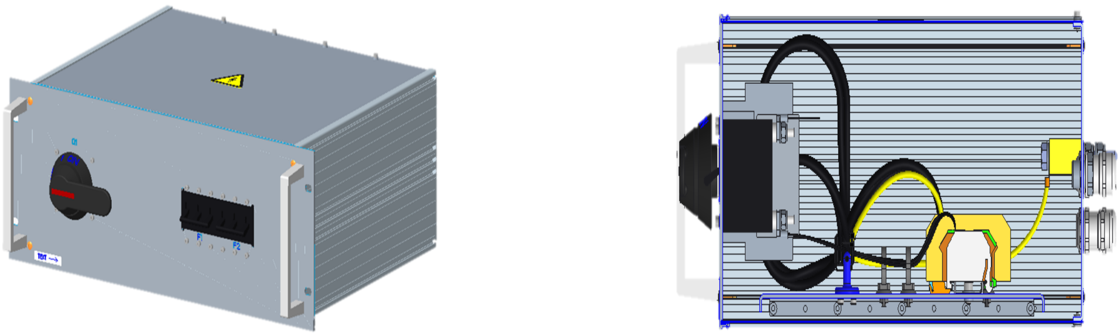

**Figure 2.5:** PDU1, front (a) and open side (b) view.

## 2.2 Functions Analysis

The *Functions Analysis* is here presented as a functions structure, as explained by Söderberg (2017). See Figures 2.6.a and 2.7.a for the respective PDSs functions structure. Both functions structures have a system boundary, which includes all functions that the PDS carries and excludes systems outside of the PDS. The surrounding blue line represents the chassis which holds the functions. In the Modular PDS, these functions have close to a corresponding unit per function, while in the Integrated PDS, the functions share the common space within the respective chassis'. The functions are each represented by the blue boxes. See Table 2.1 for the explanations of the different functions' abbreviations used in the functions structures. The functions structures are presented alongside the respective PDSs product structure in Figures 2.6.b and 2.7.b. The functions structure displays what energy and information enter and exit the system and how these are transformed by the functions within each system. The product structures display a stripped picture of how the same functions are physically placed in the respective PDS.

**Table 2.1:** Functions descriptions' abbreviations.

| **Abbreviations Description** | | |
|---|---|---|
| **Abbreviation** | **Name** | **Description** |
| ECI | Electrical Connection Interface | Contains filters, bushings, outlets and lightning protection which prohibits excessive current from entering the PDS. |
| HMI | Human Machine Interface | Interface enabling user input to the PDS and information from the PDS to the user. |
| MFG | Mains Failure Guard | Circuit board consisting of algorithms that confirms if the 400 V current source exists. |
| PCP | Power Control Panel | The main interface which indicates the status of the PDS with buttons and diodes. |
| PDU | Power Distribution Unit | Distributes a voltage source, as well as monitors the load from excessive current consumption. Can either be combined within the same unit or divided into separate for AC and DC current. |
| PSI | Power Signal Interface | Distributes a voltage source, as well as communicates with external systems. |
| SOL | Switch-On-Logic | Circuit board consisting of algorithms that regulates the units within the PDS when the system is turned on and off. |
| TRAF | Transformer | Converts the 400 V current into 200 V. |

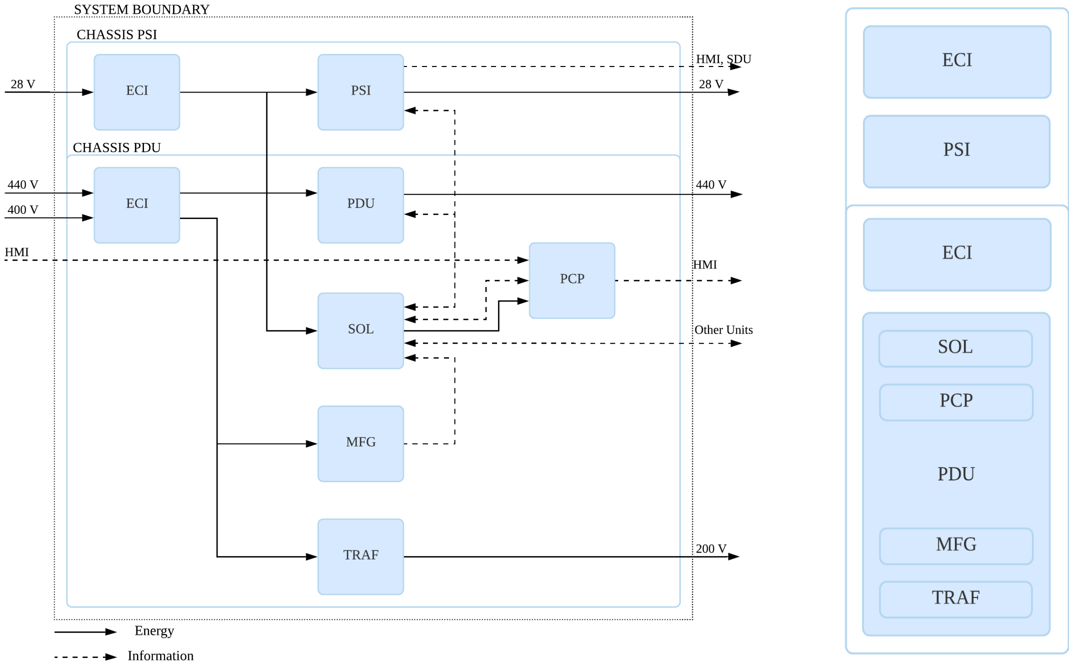


**Figure 2.6:** Functions structure (a) and product structure (b) of the Modular PDS.

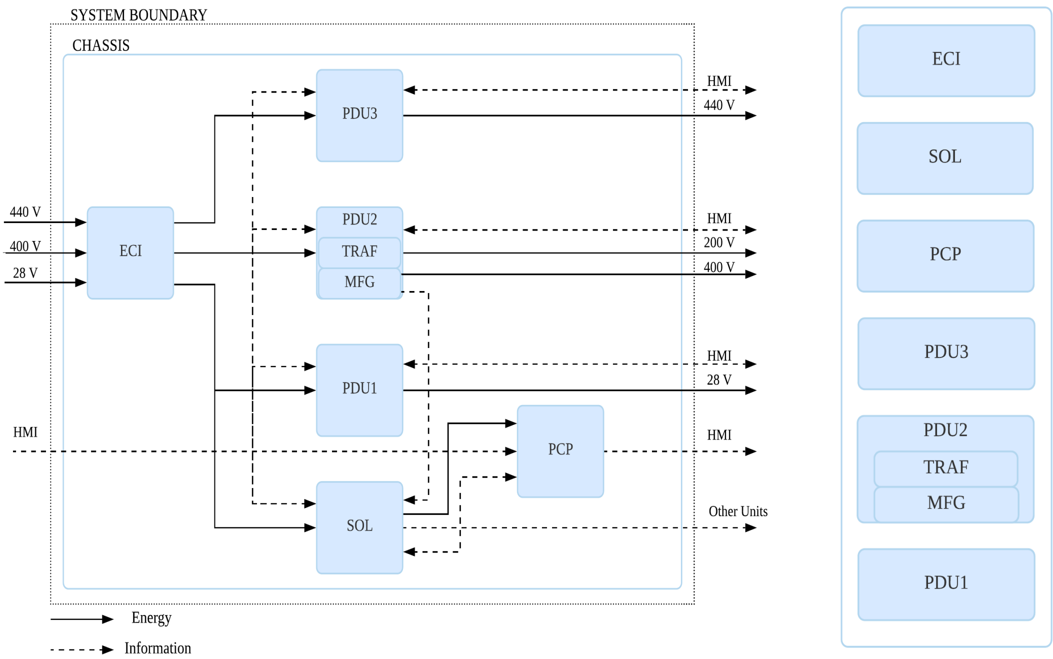


**Figure 2.7:** Functions structure (a) and product structure (b) of the Integrated PDS.

The PDSs are used for naval radars, meaning that the current entering the system is provided by the ship in which the PDS is placed. The 440 V AC and 28 V DC currents are provided by the ship. The 400 V AC current is, prior to entering the system boundary of the PDS, converted and created from the 440 V AC current in a separate transformer. For this reason, the MFG is connected to the 400 V current, because a lack of current entails both a lack of 400 V and 440 V currents. If the current is absent, the MFG communicates with the SOL which then protects the system and informs the PCP of the malfunction. The information from the PCP is communicated through diodes to those operating the radar.

Due to the many currents and information of the system, the SOL regulates and protects the units during start-up and shut-down of the system. Besides providing the PCP with energy, information from the PCP only goes to the SOL, which then distributes it to the respective function to be regulated. Additionally, the SOL communicates the status of the PDS to the external systems that together make up the whole radar system. The SOL can, therefore, be considered the operation coordinator of the PDS.

The purpose of the PDUs is to distribute a voltage source, as well as monitor the load from excessive current consumption. In the function structures, Figures 2.6.a and 2.7.a, the exiting energy from the PDUs are displayed as single arrows. In reality, the energy is divided into a connection block with several outlets to provide current to multiple external systems. Inside the PDS, the PDUs have fuses which both communicate to users if the current has exceeded by being switched off and enables users to override the system by physically holding up the switch if needed in a crisis situation.

Some of the names of the functions within the two systems differ, even though the functions are the same. For example, the function of PDU3 in the Modular PDS is incorporated into the PSI and the PDU within the Integrated PDS. Also, the TRAF and MFG are separate in the Integrated PDS but placed within the PDU2 in the Modular PDS. The two systems hence carry the same functions and are comparable, even though their physical layouts differ.

## 2.3 Economic Analysis

The *Economic Analysis* was performed to act as a base for which areas to focus on in the re-design work of the next-generation PDS. The goal of the analysis was to allocate the estimated costs for each function of the PDSs' to enable a comparison of the two, see Section 2.2 for the *Functions Analysis*. The costs of the Integrated and the Modular PDSs were extracted from Saab's Product Lifecycle Management (PLM) system, IFS (EQT, 2014). An early insight was that the PLM system was not structured to enable comparison between functions. IFS had two structures, either product or production structure. These were however not structured similarly, as the former was structured for the design engineers and the latter for the production engineers. The *Economic Analysis* comprises the total production cost (PC) of the systems, including purchased goods, man-hours, currencies, materials markup and logistics. Prior to production, Saab estimates the operations lead time to estimate a total production cost. The total outcome can be stated first post-production. The aim is for the outcome to be as close to the estimated production cost to stick to the set budget of the entire radar project.

The estimated costs of the respective PDSs were set at the time of order, and are relevant up until 2020-07 for this analysis. The Modular PDS was only ordered once in 2015, while the Integrated PDS was last ordered in 2019. Due to this short and economically stable period of time, the costs of the Modular PDS have not been re-calculated in regards to monetary inflation. Note how the exact costs could not be shared in this report as they were company confidential.

### 2.3.1 Production Cost of the Integrated PDS

The estimated production cost of the Integrated PDS is presented in Table 2.2. The cost structure collected from Saab's PLM system divides the product structure into levels, with zero being the highest. Level 0 refers to the operations costs related to assembling the other levels during production. For the Integrated PDS, Level 0 also includes some mechanical parts for assembling the top and bottom chassis. Level 1 consists of the PDU and the PSI, as they represent what is contained within its two chassis. The MFG, PCP, SOL, and TRAF are placed within the PDU and their respective costs were extracted from the PDU's total cost. Hence these units are Level 3 or 4. This separation of costs was made to better compare to the Modular PDS, as it was not possible to compare functions. As the ECI is a collection of filters, bushings, outlets, and lightning protection, it was difficult to connect one cost to that function. The costs of the ECI was therefore included within Level 1 of the PSI and PDU. See Figure 2.6.b for a visual display of the product structure.

**Table 2.2:** Estimated production costs of the Integrated PDS.

| **Estimated PC of the Integrated PDS** | | |
|---|---|---|
| **Unit** | **Level** | **% of PC** |
| PDS | 0 | 1,3 |
| PSI | 1 | 20,1 |
| PDU | 1 | 64,6 |
| MFG | 3 | 0,7 |
| PCP | 3 | 8,8 |
| SOL | 3 | 4,5 |
| TRAF | 4 | 0,02 |
| **SUM** | | **100** |

The cost distribution of the Integrated PDS in Table 2.2 shows that the PDU stands for the majority of the estimated production cost. The costs related to the PDU are all of the components placed within the PDU chassis, thus the high percentage of the total estimated production cost for the PDU is credible. The same goes for the PSI which also has its own chassis and carries the rest of the functions.

Realizing that the chassis and mechanical parts of the two units were a large contributor to the total production cost, Table 2.3 presents the estimated production costs of the Integrated PDSs chassis and mechanical parts. All cabling and electrical components have been excluded to display how much of the total estimated production cost it made up.

**Table 2.3:** Estimated production costs of the Integrated PDSs chassis and mechanical parts

| **Estimated PC of the Integrated PDSs chassis and mechanical parts.** | |
|---|---|
| **Unit** | **% of total PC** |
| PDS | 1,3 |
| PSI | 17,8 |
| PDU | 51,7 |
| **SUM** | **70,8** |

Even though the main function of the PDS is to electrically distribute and control current, the main cost driver of the product is mechanical, making out 70,8 % of the total estimated production cost. Additionally, Table 2.3 also shows how that cost is allocated within the PDS. Similar to the results of Table 2.2, the PDUs cost contribution is still a majority, which is understandable.

### Cost Outcome of the Integrated PDS

The Integrated PDS has been produced three times during 2019 with varying outcome costs. The variations depend on what other products were produced at the same time, enabling Saab to purchase larger quantities of the components to a lower price. A mean of the outcome cost for 2019 was calculated to be used for the analysis. It was deemed most fair as the outcome production times were expressed in an average of these three produced Integrated PDSs. The average consumed production hours were 13,1 % more than the estimated production hours. Yet, the total outcome production cost of the Integrated PDS was only 1,1 % higher than the total estimated production cost. The increased production hours should entail an outcome production cost of 10,3 % more than the estimated production cost.

### 2.3.2 Production Cost of the Modular PDS

The estimated production cost of the Modular PDS is presented in Table 2.4. Again, Level 0 refers to the operations costs related to assembling the other levels together during production. Level 1 consists of the three PDUs, the SOL, the Rack carrying the 19-inch units' chassis, Internal Cabling within each 19-inch chassis, and System Cabling drawn between the units and from them to the outlets. The mechanical parts required for top-level assembly are embedded within the Rack's and the respective 19-inch chassis' levels. The MFG and TRAF are placed within the PDU2, see Figure 2.7.b, and are therefore extracted from the cost of PDU2, hence they are Level 4. The cost of the PCP is included in the Rack's cost, hence it is Level 2. Same as for the Integrated PDS, the function ECI is a collection of filters, bushings, outlets, and lightning protection. This makes it harder to connect a specific cost related to those components as they are incorporated into different units or placed within the rack.

**Table 2.4:** Estimated production costs of the Modular PDS.

| **Estimated PC of the Modular PDS** | | |
|---|---|---|
| **Unit** | **Level** | **% of TC** |
| PDS | 0 | 15,3 |
| PDU1 | 1 | 7,7 |
| PDU2 | 1 | 13,0 |
| PDU3 | 1 | 16,4 |
| Rack | 1 | 15,4 |
| System Cabling | 1 | 2,2 |
| Internal Cabling | 1 | 10,5 |
| SOL | 1 | 14,1 |
| PCP | 2 | 4,6 |
| MFG | 4 | 0,5 |
| TRAF | 4 | 0,3 |
| **SUM** | | **100** |

The Modular PDSs cost drivers were more evenly distributed across the different units, in comparison to the Integrated PDS, which is reasonable due to the modularity of its product structure. When performing the *Economic Analysis* for the estimated production cost of the Modular PDS, it became evident that there is a difference between the product structure and production structure, which the estimated costs are assigned to. The level called Internal Cabling in Table 2.4 is a cost summation of cables used within several of the 19-inch chassis, which should be separated into the cost of the units they belong to. The same goes for System Cabling, which is a cost summation of cables connected between the 19-inch chassis within the Rack. Table 2.5 presents the estimated production costs of the Modular PDSs chassis and mechanical parts. All cabling and electrical components were excluded to display how much of the total estimated production cost is made up of mechanical parts. Note that the PDS comprises of costs related to top-level assembly.

**Table 2.5:** Estimated production costs of the Modular PDSs chassis and mechanical parts.

| **Estimated PC of the Modular PDSs chassis and mechanical parts** | |
|---|---|
| **Unit** | **% of total PC** |
| PDS | 28,0 |
| Rack | 15,4 |
| SOL | 7,0 |
| PDU1 | 6,6 |
| PDU2 | 11,0 |
| PDU3 | 11,1 |
| **SUM** | **79,0** |

The resulting summation of 79,0 % in Table 2.5 is a huge part of the total production costs, which was not possible to make out of the result presented in Table 2.4. Although, these costs were surprising, they were not unreasonable due to the modular structure of its chassis'.

### Costs Outcome of the Modular PDS

The outcome cost of producing the Modular PDS was 32,1 % higher than the estimated production costs. The same reasoning for the Integrated PDS goes, that the increased costs relate to purchase quantity and production hours. As previously mentioned, the Modular PDS has only been produced once. Evidence of the increase partly points to issues in first-time-production, according to design engineers at Saab. E.g., alterations to the design had to be made as a result of mistakes in fulfilling the requirements of some components.

The outcome of the production hours showed an increase of 33,3 % in comparison to the planned hours. Again, the reason is likely the adjustments necessary for the alterations made, leading to exceeding the estimated planned hours. The increased production hours map closely to the increased outcome production costs, which should mean that the estimated costs that were not related to pure production hours were lower than expected.

### 2.3.3 Comparison of Production Costs

In Table 2.6, the costs presented are expressed in percentages of the estimated production costs and outcome of the Integrated and Modular PDS. The Integrated PDS's estimated production cost was set as reference due to confidentiality reasons. The estimated production costs should only differ from the outcome production costs in two aspects, the first being the purchase prices and the second being the production hours. As mentioned, the purchase prices of goods differ depending on the purchased quantity. The outcome production hours can depend on many factors. For the Integrated PDS this might differ as it was produced on three different occasions, while the Modular PDS was only produced once.

**Table 2.6:** Estimated and outcome PC of both systems.

| **Estimated and Outcome PC** | | |
|---|---|---|
| | **% Estimated PC** | **% Outcome PC** |
| **Integrated PDS** | 100,0 | 101,1 |
| **Modular PDS** | 140,2 | 185,1 |

Table 2.7 shows the estimated and outcome production hours presented in percentages of the estimated hours of the Integrated and Modular PDS, where the Integrated PDS's estimated production hours was set as reference.

**Table 2.7:** Estimated and outcome production hours of both systems.

| **Estimated and Outcome Production Hours** | | |
|---|---|---|
| | **% Estimated Hours** | **% Outcome Hours** |
| **Integrated PDS** | 100,0 | 113,1 |
| **Modular PDS** | 115,2 | 153,6 |

Speculation regarding the Integrated PDS emerged when it's low outcome cost was compared to what it should have been expected to be calculated from the production hours. The Integrated PDS's average outcome production cost and average outcome production hours should coincide to a greater extent than the 1,1 % cost increase versus the 13,1 % increase in hours, which should increase the total production cost with 10,3 %. A possible explanation is that the estimated cost for the purchased goods turned out to be less expensive than calculated, which then covered for the exceeded amount of planned production hours.

The Modular PDS's outcome cost was not based on an average but on a one-time production. It was estimated to be 40,2 % more expensive than the estimated

Integrated PDS's cost, but ended up with an outcome of 85,1 % increase. The increased production hours added to the estimated production cost of the Modular PDS amounts to 70,2 % increased costs compared with the estimated production costs of the Integrated PDS. Again, this outcome could be the result of either production hours or purchasing costs. In this case, it meant that the purchase cost also exceeded the estimations, as well as the planned hours, thus explaining the large outcome cost. The Modular PDS was estimated to take about 2 % longer to produce than the Integrated PDS's average outcome production time. This is a relatively little difference, which might have been motivation enough to go ahead with the development and production. However, the outcome is way higher and it is unknown how much is because of first-time-errors, due to the Modular PDS's first-time-production, and how much is the actual output.

A phenomenon regarding streamlining in production is the learning curve. Cunningham (1980) presented in his article *Management: Using the learning curve as a management tool*, that the direct man-hours per unit decrease exponentially relative to the cumulative production in terms of units. He stressed that the time aspect is not as vital as the amount of produced units. The benefits to enjoy as a result of this are economies of scale, increased efficiency, and productivity (Cunningham, 1980). This is relevant to Saab, as their production volume is low. A point of reflection is that the benefits of modularity was sought for when producing the Modular PDS. According to Saab engineers, it was supposed to carry most of the development costs, and first-time errors. Some costs might still be such, but as the product is not modular in that sense, the upcoming productions of the same Modular PDS should still be at least as expensive as the estimated costs. The required production hours are much higher than what was calculated by Saab's production personnel. If there is an issue regarding their models or if this issue is connected to the complex nature of these products is unknown, but should be investigated.

It is difficult to compare a one-time production to a product that has been in production several times and for several years. The aspect of modularity, to carry first-time costs, is also not fully applicable to the Modular PDS's case as each 'modular' unit are de facto not modular as they each require project unique alternations. The conclusion of the analysis was hence that the major cost-drivers, i.e. the chassis and mechanical parts of each respective system should require a re-design for upcoming generations. Furthermore, the new design should better fit customization and ease production, as this is a large contributor. Lastly, a recommendation is that Saab reconsiders the PLM system structure to better match the product structure to enable improved future economic analysis'.

# 3

# Identify Customer Needs

The first step of the Product Development Process, according to Ulrich and Eppinger (2012), is to *Identify Customer Needs*. The aim of the interviewing process was to gather the different stakeholders' needs and requirements and to understand what their challenges were with each PDS. This data was important as it was later going to be interpreted in terms of customer needs and requirements using the KJ method to use a structured approach, (Iba, Yoshikawa, and Munakata, 2017). This interpretation would later be used for the *Concept Requirements*, which in turn would guide the concept development phase.

## 3.1 Interviews

Interviews were held with different actors at Saab with diverse knowledge of the two systems. Interviewees were decided to be design engineers, industrial engineers, service leaders, system managers, customers, and end-users. First off, three design engineers, two of them were electrical engineers and one was a mechanical engineer, were interviewed on the two designs' differences and similarities, benefits and drawbacks. One interview was held with two production engineers on the production process of the systems. Furthermore, one Service Lead was interviewed on the verifying and testing of the systems. The Service Lead also gave input on end-user interaction and different user situations as they were not possible to interview due to confidentiality reasons. Lastly, a System Lead and a System Design Manager were interviewed to gain a greater understanding of the reasoning behind the transfer from an integrated to a modular product architecture.

As the production volume of the PDS is relatively low, the amount of people involved in each step of the process are few. The amount of interviews were hence relatively few and aimed instead at being as qualitative as possible. The interview questions required about 30 minutes of questioning but the interviews were scheduled for one hour, which allowed probing to explain and clarify. The interview results are presented in Appendix A with the main takeaways of each interview, grouped into roles and then further into the relevant areas of discussion.

The interviews were documented by taking notes, which were later sent to the interviewees for them to approve or adjust if needed. For GDPR reasons, the interview notes were later deleted at the time of thesis completion (June 12th 2020). Interviewees had in some cases prepared photos of the systems or sent them post interview to refer to specific statements. These were not included as they contained classified information. A goal was to observe interviewees while interacting with the systems, alongside the interviews, for contextual purposes and to gather non-verbal information. This too was however not possible because of classification issues. A tour through production was however given, where similar Integrated PDSs, and a 19-inch solution not aimed for power distribution, were produced. This tour gave insight to how the assembly is performed and the space limitations the personnel have with each PDS.

## 3.2 Compilation of Interview Results

A summary of how the two PDSs performed on the aspects discussed by the interviewees, see Appendix A, is presented in Table 3.1. The table presents a number of *Performance Parameters*, which were identified as the most important aspects. The parameters were divided into two sections. The top section of the parameters were deemed to affect the cost the most and were hence prioritized due to the thesis' cost-focus. The bottom parameters also affect the costs, but not to the same extent. The Integrated PDS was set as the reference as to be consistent with the *Economic Analysis* in Section 2.3. The Modular PDS was hence evaluated in reference to Integrated PDS's performance: worse than (-), or better than (+).

The parameters in Table 3.1 are more or less interlinked with each other, e.g. *Intuitiveness* and *Serviceability* affect each other as intuitive designs are quicker to perform service on, according to the Service Lead. Likewise, *Cabling*, *Materials* and *Production Cost* are also connected. Another important input is that the development cost and production cost of the Modular PDS ought to be lower than the current outcome if it would have been produced as many times as the Integrated PDS. Table 3.1 shows that the Modular PDS performed worse than the Integrated PDS with the exception of five parameters: *Flexibility*, *Standardization*, *Intuitiveness*, *Serviceability* and *Uniformity (Design)*. Hence, in a short-term perspective, it seemed more cost-effective to produce a new updated version of the Integrated PDS, which would perform better on those five performance parameters. Although, standardization and integration are each other's opposites, the other parameters should be possible to design for. However, *Uniformity* with other Saab products might be possible to achieve even though it is not a 19-inch chassis, if one only focuses on the exterior, but true uniformity would require a 19-inch solution. With that said, an integrated design is hard to standardize and Saab has locked in the 19-inch design, which would make it the best solution for achieving uniformity.

**Table 3.1:** A comparison of how the two PDSs perform on different parameters.

| **Performance Comparison** | | |
|---|---|---|
| **Performance Parameters** | **Integrated PDS** | **Modular PDS** |
| Development Cost (DC) | 0 | - |
| Production Cost (PC) | 0 | - |
| Cabling (PC) | 0 | - |
| Materials (PC) | 0 | - |
| Flexibility (DC) | 0 | + |
| Standardization (DC) | 0 | + |
| Intuitiveness | 0 | + |
| Reachability | 0 | - |
| Serviceability | 0 | + |
| Size | 0 | - |
| Spaciousness | 0 | - |
| Uniformity (Design) | 0 | + |
| Visibility | 0 | - |
| Weight | 0 | - |

One reflection was that a more progressive solution would be to stick with the 19-inch solution to keep the positive performances: *Flexibility*, *Standardization*, *Intuitiveness*, *Serviceability*, and *Uniformity*, but to focus on improving the cost aspects. The most costly production cost was *Cabling*, as a natural cause of modularity, which could be minimized if this were to be adapted in the new design. Regarding the remaining negative aspects: *Materials*, *Reachability*, *Size*, *Spaciousness*, *Visibility*, and *Weight*, it should be possible to develop a more optimized design.

# 4

# Concept Requirements

The second step of the Product Development Process by Ulrich and Eppinger (2012) is to establish a target specification. This is supposed to be revised continuously during the development process and lead to a final requirements specification which the developed product is to be verified against. In this thesis, only one requirements specification is presented for the to-be-developed concept, including both the standards that Saab's products comply with, and the customer needs and requirements. The customer needs and requirements are a mix of the learnings from Chapters 2 and 3 with monetary goals and user needs. The final requirements specification was, therefore, made into a *Concept Requirements Specification* which is presented in Appendix B.

A *need* in the *Concept Requirements Specification* is a non-critical criterion from users and customers, while a *requirement* is a non-negotiable criterion. These are referred to as *N* or *R*. The requirements should be measurable to enable verification, while needs are not as they are less tangible and more subjective. The needs and requirements of the *Concept Requirements Specification* were separated into two types of criteria: externally decided standards, which Saab's products have to comply with, and criteria of customer needs and requirements. How these were gathered and what they entail is presented in the following sections.

## 4.1 External Standards

The included criteria from external standards mainly regard the PDSs physical environment, i.e. climatic and mechanical requirements. Climatic environmental requirements regard temperatures, air pressure, humidity, fungus and water ingression. Mechanical environment requirements regard vibrations, shock and ship motion. All of these criteria are based on a number of standards for naval equipment. The criteria presented in Appendix B were retrieved from Saab's naval product requirements which related to the PDS specifically. The PDS is in a so called 'sheltered environment' as it is placed in a machine room below deck. This entails a protection against precipitation, ice, sand, etc., and that the system mainly operates in room temperatures.

The PDS's performance in terms of functions were not included in the *Concept Requirements Specification* as they were both confidential and non-crucial to carry out the development work. Saab also complies with electrical environmental requirements from various standards covering EMI (Electro Magnetic Induction)/EMC (Electro Magnetic Current) requirements. No such requirements were included as they do not affect the mechanical design substantially on a concept level. Because of the thesis' limited time for testing and verifying the requirements, the design decisions were instead made in agreement with Saab engineers who could justify possible solutions. This is the reason for the *Verification Method* being set to *Expert assessment*.

## 4.2 Customer Needs and Requirements

Other than the standards, criteria were also gathered from different stakeholders. The interviews were the main source of information on the customer and user needs and requirements, see the results presented in Chapter 3. The interviewees were different stakeholders in development, production and service of the PDS. They shared their perception of the product's user satisfaction and usability in their particular role, along with end-user interaction. This was then used as the base for the *Performance Parameters* as presented in Table 3.1 in Section 3.2. These parameters were then included as criteria in the *Concept Requirements Specification* in Appendix B. Note that only top-level cost criteria, i.e. development and production cost, include a target value requirement. Their lower-level criteria were deemed too hard to measure and were instead set to be assessed subjectively, rather than calculated individually, as they are each part of their respective top-level cost.

The *Verification Method* for the *Cost* criteria was set to be a *Cost estimation*, based partly on the knowledge and information gathered in the *Economic Analysis* in Section 2.3, and partly on the knowledge of Saab personnel. Regarding the *Usability* criteria, the method was set to be a *Subjective assessment* as it would be used to subjectively weigh different concept solutions against each other. The *Target Value* for these criteria were set to be better than or equally as good as ($\geq$) the PDS which performed best in Table 3.1 in Section 3. Again, the interviewees would be asked about preferences when needed. As for the *Design* criteria, they are easily measured in the CAD model. The *Cost* criteria were set to requirements ($R$) is the new concept should cost less in both development and in production. The *Usability* criteria were set as needs ($N$) as they were not the main focus of the thesis and could not be measured. The *Design* criteria were set as requirements as they were the allowed for maximum, according to the same Service Lead advised in the interviews.

# 5

# Generate Product Concepts

The third step of the Development Process, according to Ulrich and Eppinger (2012), is to *Generate Product Concepts*. To systematically explain this large step in the process, it was broken down into its parts, all referring to the methodology by Ulrich and Eppinger (2012): *Clarifying the Problem*, *Internal and External Sourcing* and *Explore Systematically*. *Clarifying the Problem* was done up until this point in Chapters 1-4 as it was important to understand the complexity of PDSs as early as possible. To generate product concepts, idea generation in terms of *Internal* and *External Sourcing* was performed. The *External Sourcing* in this thesis included a literature study of product architecture, benchmarking solutions, and frequently gathering know-how from Saab employees. The idea was to gain insight into what type of solutions would fit Saab the best. Furthermore, *Internal Sourcing* mainly regarded brainstorming both individually and together with Saab employees on both a system level and on detail level. Finally, to *Explore Systematically* implies that the process of generating and creating total concepts should be done in a systematic manor, as to not leave out possible solutions. This was ensured by making a simplified Morphological matrix of the possible generated product concepts.

## 5.1 External Sourcing

The *External Sourcing* includes a literature study and benchmarking. The literature study focused on product architecture and how it is applicable to Saab. The benchmarking explored possible solutions existing on the market and within Saab.

### 5.1.1 Product Architecture

When choosing a product architecture, there are two extremes: an integrated or a modular design. The two are each other's opposites and are more or less applicable depending on the product. Hybrids of the two extremes are common to gain the benefits of both. Modularization means that the physical interfaces between parts in a product are standardized, which decreases the product complexity by tying a module to a single function, according to Ulrich (1995). Modularization goes hand-in-hand with platform planning. Magnusson and Pasche (2014) explained that a product platform is the product family offering based on common modules, with some distinctive differentiating parts. Companies modularize to gain market share through delivering a wider product offering to several market segments while using minimal resources. The goal is to gain economies of scale, enable mass customization, shorten product development lead-times, increase flexibility, and much more according to several source such as Ulrich (1995), Robertson and Ulrich (1998), Magnusson and Pasche (2014), Lau, Yam, and Tang (2011). What Magnusson and Pasche (2014) underlined was that while the ultimate goal is to gain economies of scale and mass customization, it is only a possibility if the production volume is larger. As for an integrated design, Ulrich (1995) discussed the ability to design for a central optimization of a product's performance, and that integration can enable function sharing and geometric nesting to optimize e.g. size and mass. An integrated design is a more favorable choice when production volume is low, when size and mass are important parameters to keep low, and when modularity is not economically feasible. Lastly, an integrated design can always offer infinite product variety (Ulrich, 1995).

Regarding when to apply which structure was covered by Magnusson and Pasche (2014, p. 448), who set up three scenarios for when to apply which product structure, depending on the market demand and change for the product. Change here refers to both 'technological change' and 'change in customer demand'. Magnusson and Pasche (2014) also stated that as the nature of platform development is long-term and slow-moving, a company whose product has a low rate of change could benefit from applying such strategy to gain the benefit of re-use in design.

1 *"If customers demand a high degree of customization, and the rate of change is high, firms may choose to adopt modular product architectures."*

2 *"In case customers favors cost-efficient functionality and the rate of change is low, firms should rather focus on the establishment of product platforms."*

3 *"In cases where there are very high demands for customization, in combination with a willingness to pay a premium for this, it may actually be the case that modularization and product platforms altogether constitute obstacles for achieving the needed product flexibility."*

What this implies for Saab was difficult to pin-point as the PDS is part of a larger system and that either modularization or integration strategy affects more than solely the PDS. Some assumptions could however be made regarding more or less suitable directions. Saab's customers high demands on customization, along with their willingness to pay, comply mostly with Magnusson and Pasche (2014) statement [3], meaning that Saab might benefit most from an integrated design. The low production volume enhances this conclusion as the benefits of economies of scale, mass customization, etc. can not be gained. Regarding the price, Saab's customers do not purchase the PDS itself, but rather the entire radar system which is of high quality and carries a matching premium price. Furthermore, the rate of technological change was assumed low, as the Integrated PDS has been in production for decades with no design updates made. The rate of change in customer demand was perceived high as for each project, new product requirements were set. The PDS also does not have restrictive volume nor mass requirements. Hence, according to the literature, the PDS would hence benefit from a flexible design, utilizing platform strategies to benefit from re-use. Saab has tried to benefit from this by offering this base-product PDS with minimal production modifications per project, but has failed to deliver it in a cost- and time-effective way.

### 5.1.2 Benchmarking of COTS

The results of the benchmarking activities are presented in this section, which mainly covered the availability of COTS-products. Table 5.1 presents the findings of suppliers of PDUs, with the limiting factor that they had to comply with military standards. They are listed by country of origin (COO) as the System Design interviewees discussed some complexities in supplying from certain countries, see Appendix A. Most suppliers were found using Google searches of 'Military' and 'PDU' or 'Power Distribution Unit'. The only exception was MilDef Group AB (2020) whom supply DC PDU COTS units, while it is not their expertise. They were included as Saab already purchases a lot from them and they have a close supplier-buyer relationship.

Most products supplied through the companies in Table 5.1 lack some crucial aspect, e.g. the ability to control, measure and monitor its functions, or that they are not a 19-inch standard design. Another aspect was that the found COTS PDUs had a set amount of in- and outlets, whereas the PDS requires potentially as many variants as there are projects. All suppliers, however, offer customizable solutions (based on their COTS offerings), which Saab employees call 'MOTS', i.e. Modified-Off-The-Shelf products. After further discussion with the electrical engineers working on products such as the PDS, the following was understood: Suppose there are feasible suppliers of both DC and AC PDUs. The PDS requires at least one DC PDU and one AC PDU with the ability to be controlled and monitored. This would either have to be a MOTS or an in-house developed unit, as this is not a COTS availability. If a project would require additional capacity, COTS units could be stacked onto that unit for a modular supply.

Many of the identified suppliers were from the USA, whom had a greater offering of AC COTS units. An issue with this is that regarding AC there are many different standards, according to the electrical engineers at Saab. The American standard is 115 V and 60 Hz, while Saab uses 230 V and 50 Hz. The word 'restricted' was hence added to some offerings. Out of the 11 companies offering AC COTS units, four of them were restricted and all but one (not restricted) were of American brands. Regarding design, only one supplier did not comply with the 19-inch standard, which was the Swiss supplier Enercon Technologies Europe AG (2020).

**Table 5.1:** Benchmarking results of suppliers of PDUs developed for military applications by country of origin (COO).

| **Suppliers of COTS PDUs for Military Application** | | |
|---|---|---|
| **COO** | **Company Name** | **Offerings** |
| CHE | Enercon Technologies Europe AG (2020) | COTS: DC<br>Customize<br>Not 19-inch standard |
| IL | Alexander Schneider (2020) | COTS: DC & AC<br>Customize |
| SWE | MilDef Group AB (2020) | COTS: DC<br>Customize |
| USA | Acumentrics (2019) | COTS: AC<br>Customize |
| USA | API Technologies Corp. (2020) | COTS: AC restricted<br>Customize |
| USA | Arnold Magnetics Corp. (2020) | COTS: DC & AC restricted<br>Customize |
| USA | Eledctro-Cord (2020) | Customize |
| USA | Electromet Corp. (2020) | COTS: AC restricted<br>Customize |
| USA | Intellipower, Inc. (2020) | COTS: DC & AC<br>Customize |
| USA | Marway Power Solutions, Inc. (2020) | COTS: AC<br>Customize |
| USA | Nova Electric (2020) | COTS: DC & AC restricted<br>Customize |
| USA | Powergrid$^{M}$ (2020) | COTS: DC & AC<br>Customize |
| USA | Raritan Inc. (2020) | COTS: AC<br>Customize |
| USA | UEC Electronics (2020) | COTS: AC restricted<br>Customize |

Other than the power distribution offering, some companies also added to the benchmarking with other clever solutions. For example, Marway Power Solutions, Inc. (2020) had a solution for membrane switches, which was an interesting solution for this thesis. Also, Powergrid$^{M}$ (2020) had an 'Intelligent Stacking' solution which allowed for stacking the power supply in a modular way to fit ones needs. A similar type of stacking solution was also provided by MilDef Group AB (2020). The details of these findings were not investigated further but were deemed viable solutions to incorporate in potential concepts. When finding modular, 'stackable' solutions and consulting Saab employees, other products of their knowledge surfaced. A Saab Group company in Arboga has attempted producing modular PDUs. However, after consulting the developers at Arboga, the modular PDUs were concluded not suitable for a naval PDSs, as they have different requirements and lacked some essential functions. This could however be an inspiration for when developing concepts. If applying COTS solutions, there has to be a MOTS or an in-house developed unit included, as discussed. This modular unit could act as such.

To further understand which suppliers were feasible, several Saab employees at the purchasing department were consulted. They explained that both the quality and the purchasing departments have to be involved when assessing suitable suppliers and products. This requires two people, one from each department, and takes about 150 to 200 working hours to make an assessment, find a suitable solution and supplier, to result in a finalized contract. It also requires some traveling to visit the supplier in person for a quality inspection. The list in Table 5.1 would act as their base for who to contact.

## 5.2 Concept Generation

The results of the external sourcing activities, along with internal sourcing in terms of brainstorming, led to five general concepts on a system level. The five concepts, *Alpha*, *Bravo*, *Charlie*, *Delta*, and *Echo*, are presented in general and are not developed in detail. In Figure 5.1, the concepts are placed on a spectrum, from modularity to integration to visualize their diverse architecture. The concepts *Alpha* and *Echo* are on each side of the spectrum, whereas *Bravo*, *Charlie*, and *Delta* can be considered hybrids of the two. The spread of the concepts was made to explore the two extremes and their hybrids, as they have their respective advantages and disadvantages. Seeing that nor the Modular or Integrated PDS fully fulfills the new requirements of the future generation PDS, they were not included as concepts. *Alpha* and *Echo* were therefore generated as new alternatives in their place.

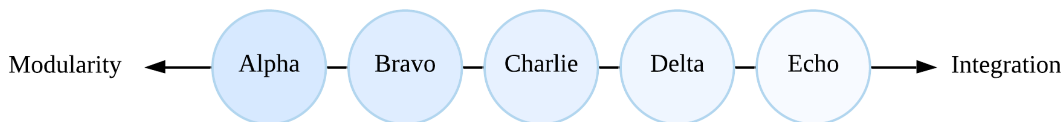


**Figure 5.1:** The generated concepts placed on a scale from modularity to integration.

The concepts were generated though choosing between different chassis and units. There were two chassis alternatives: a 19-inch standard COTS or an unique chassis, which would be developed in-house. There were three alternatives for the function carriers, i.e. units: 19-inch standard COTS, in-house developed 19-inch units, or in-house developed integrated units. The concept sphere of possible options are illustrated in Figure 5.2.

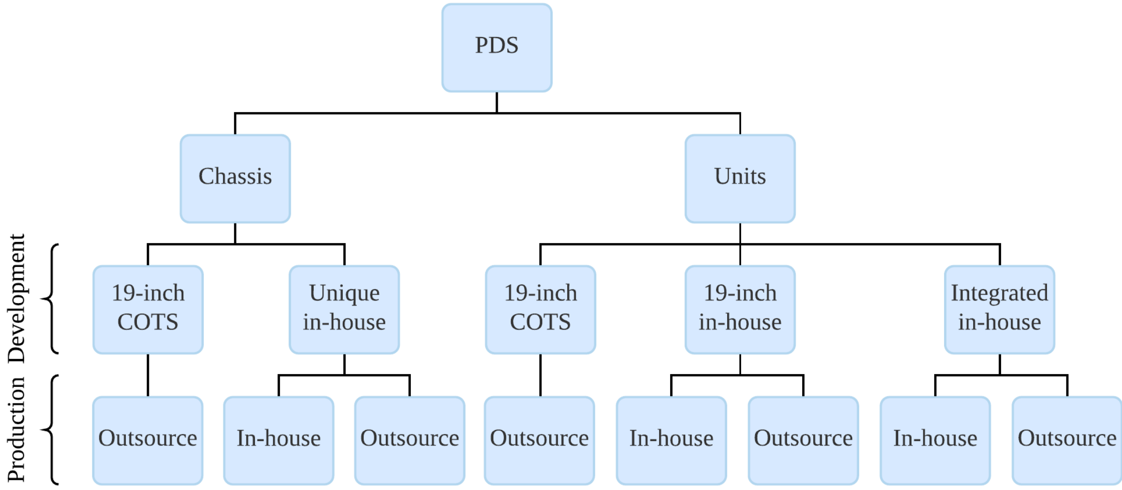


**Figure 5.2:** The generated concept sphere.

When outsourcing either development or production, the risks are generally related to communication issues, as discussed in the interviews in Appendix A. Outsourcing production could lead to problems surfacing late which could impact quality and potentially delay delivery. When outsourcing development, Saab creates a product specification that is then fulfilled by a supplier. Usually, the supplier is already producing similar products that they alter to fulfill Saab's requirements. The supplier has to be approved by Saab, to minimize conflicts with the customers. In-house development gives Saab complete control of requirements and the ability to react to issues as they occur. Moreover, if choosing in-house production, the product is likely in-house developed. In such a case, Saab has full control and mandate over the entire development and production chain, but are hence also liable for it. To instead outsource the production would release Saab resources.

Table 5.2 is a Morphological Matrix that visualizes how the different chassis types and units were combined to create the five concepts. The concepts are later in this chapter described in Sections 5.2.1-5.2.5. Note in Table 5.2 how there is no solution with a COTS 19-inch chassis and COTS units, where electronics and front and back plates are developed and produced in-house. The reason for this is that it would be the same solution as the Modular PDS which was proven to be too expensive and perform worse than the Integrated PDS, see Section 3.2. Lastly, there was a possibility of using both 19-inch COTS and in-house developed units in the same solution, which is the Bravo alternative.

**Table 5.2:** Morphological matrix of the generated concepts.

| | Morphological Matrix | | | | |
|---|---|---|---|---|---|
| | Chassis | | Unit(s) | | |
| | 19-inch COTS | Unique in-house | 19-inch COTS | 19-inch in-house | Integrated in-house |
| **Alpha** | x | | x | | |
| **Bravo** | x | | x | x | |
| **Charlie** | x | | | x | |
| **Delta** | x | | | | x |
| **Echo** | | x | | | x |

### 5.2.1 Alpha

Concept *Alpha* has a standardized 19-inch chassis with minimal in-house development and production, preferably all COTS products, see Figure 5.3. Saab would order the chassis and components from suppliers and solely assemble the parts to a complete PDS. All possible development costs would in this case be in the hands of a supplier. The strengths of this concept is that the use of COTS would entail a truly modular solution, where e.g. the amount of PDUs can more easily be regulated depending on each costumers' needs. If a customer were to require additional capacity, Saab has the possibility to add another COTS PDU, and stack it along with the others. This modular solution minimizes development and production costs and the units are better size optimized.

However, this concept is only possible if there are COTS PDUs for both AC and DC required currents, are MIL certified for military use, and that the components can be produced by viable suppliers. Furthermore, the major risk related to this alternative is that each project has widely different requirements, which affects the design in many ways. There is also the limitation where suppliers have to have COTS units that enable all functions that Saab requires. Since the PDU is a complex product, in a complex system, it is not a given that a supplier produces a product that would fit.

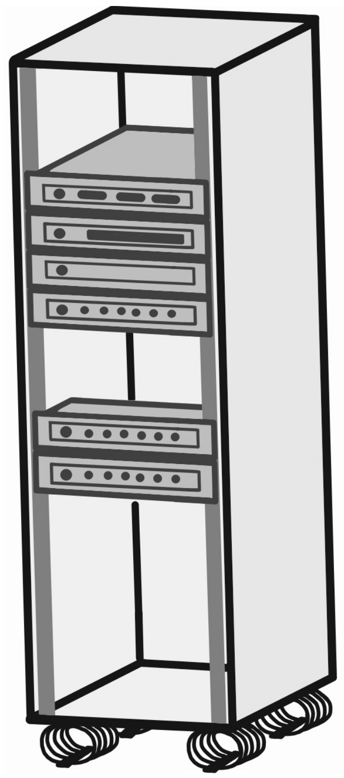

**Figure 5.3:** The generated concept *Alpha*.

### 5.2.2 Bravo

The *Bravo* concept is a modular solution in a 19-inch standard chassis with partly COTS units and partly in-house developed units, see Figure 5.4. The standardized 19-inch chassis makes the PDS compatible with all COTS units on the market that has the same standard. As better COTS units are being developed and released to the market, can they easily be implemented into the PDS when technology advances.

The combination of the two unit types enables Saab to separate the functions in terms of complexity. The less complex functions could be carried out using COTS units, while the more specialized functions required by the customer, would be designed by Saab. *Bravo* combines the benefits of simple, size optimized COTS units, with the possibility to create a customer specific solution. When designing a PDS for a new customer, the alterations would be limited to the in-house produced units, which minimizes development costs. Note how there might be limitations in the market of 19-inch COTS units, same as was discussed for *Alpha* in Section 5.2.1.

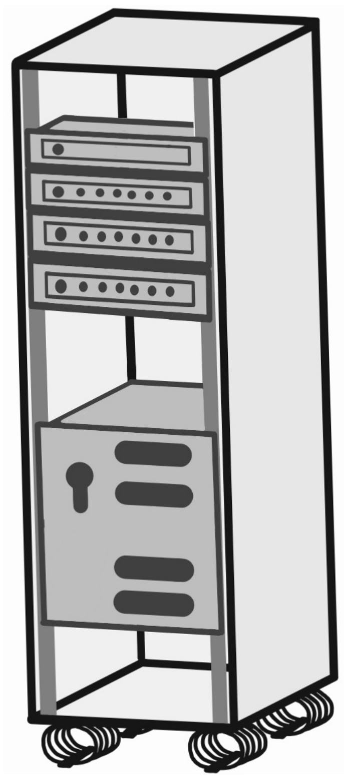

**Figure 5.4:** The generated concept *Bravo*.

### 5.2.3 Charlie

A 19-inch chassis with all in-house developed 19-inch units is what the *Charlie* concept consists of, see Figure 5.5. As previously discussed, the 19-inch standardized COTS units used in the Modular PDS have a maximum height of 4U and has to be altered and reinforced to carry the weight of the required components. The units in the Modular PDS were described as cramped by the Design and Industrial Engineers in the interviews in Appendix A. Therefore, the units in the *Charlie* concept are designed to fit in a 19-inch standardized rack, carry the weight of their components, and are not limited in height to increase spaciousness and save costs compare to the Modular PDS.

Instead of having many small units, *Charlie* has fewer but larger ones. Additionally, the larger units in *Charlie* would limit the amount of cabling between the units and would create more space within each unit compared to the Modular PDS. *Charlie* has the ability to combine the advantages of the Integrated PDS with the standardization of the Modular PDS's rack.

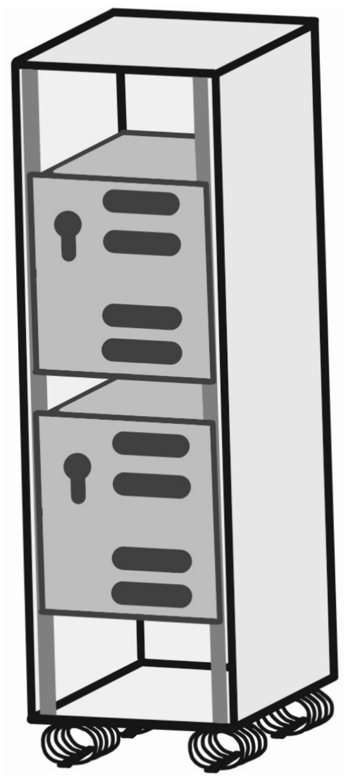

**Figure 5.5:** The generated concept *Charlie*.

### 5.2.4 Delta

*Delta* is the concept which combines a 19-inch chassis with an integrated unit inside, see Figure 5.6. It means that the internal structure of the Integrated PDS is placed within a 19-inch chassis. The benefit of still keeping the 19-inch solution is that the external uniformity of Saab products is sustained. Further benefit is that the same, well-functioning production method of the Integrated PDS is kept as well, which has lower cabling costs and fewer production hours. The 19-inch chassis comes in the same width but can be ordered in many different heights (in U).

In the interviews, see Appendix A, all of the Design Engineers confirmed that the components within the PDUs should be able to share a common space, as long as there is some separation to avoid EMC leakage or mistakes in assembly and service. Therefore, the unit in the *Delta* is one large integrated unit. Since the components are placed in a shared pace within the chassis, collectively mounted on a back plate and not in individual units, increasing the number of components would be easier due to it's spaciousness. A drawback of the *Delta* design is that there is not a large technological advancement. However, the production cost is low and it is a safe alternative in terms of production costs.

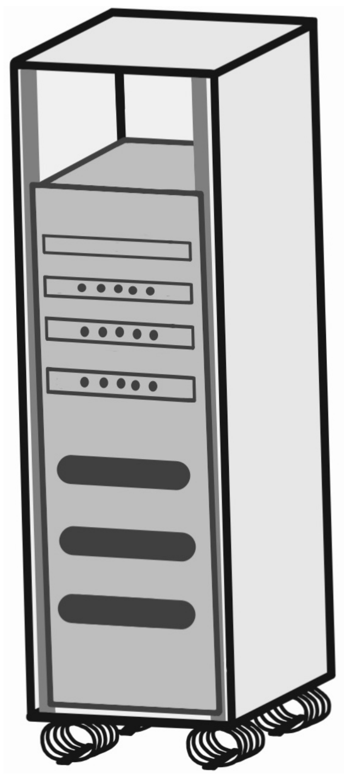

**Figure 5.6:** The generated concept *Delta*.

### 5.2.5 Echo

The fifth concept is *Echo*, which has an integrated chassis and an integrated structure inside, see Figure 5.7. This solution is in general the same as the Integrated PDS, although with a new and larger in-house designed chassis to hold and combine both the PSI and the PDU into one. As previously mentioned in Section 5.2.4, was it confirmed by all the Design Engineers in the interviews in Appendix A, that the components can share a common space. The advantage of gathering the components into one unit would improve the visibility and serviceability of the PDS, and lowering the amount of system cabling.

In the areas where the Modular PDS performed better than the Integrated PDS, see Section 3.2, the new integrated *Echo* design could be designed to perform better on those parameters. Since the Integrated PDS' chassis is unique, would it be costly to redesign and expand it in the case of a requested capacity increase. Therefore, the *Echo* chassis would be larger than the existing Integrated PDS's chassis, to leave room for increased number of components. The *Echo* concept does however not reach high technological advancement.

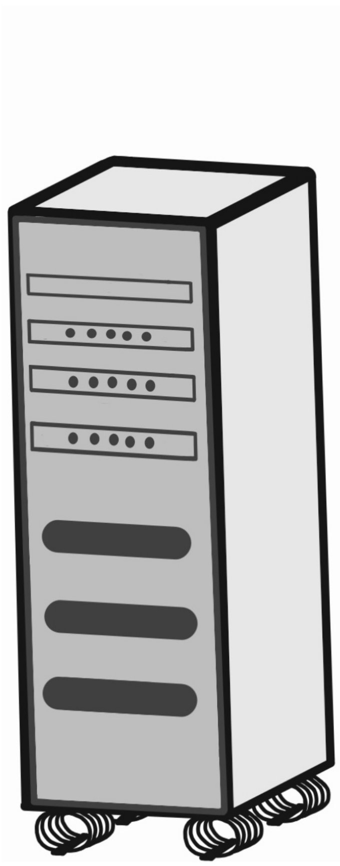

**Figure 5.7:** The generated concept *Echo*.

# 6

# Concept Selection

The next step of the Development Process, according to Ulrich and Eppinger (2012), is to *Select Product Concepts*. A common strategy used for screening concepts is to use a requirements specification to evaluate which concepts perform better than other on the different criteria. As the five generated concepts were of a system-level, the external standards set on the product would be easily complied with through detailed design. Hence, the only criteria to use for screening were those related to cost. The usability-criteria were chosen to apply when going into detailed design work, and the design criteria, dimensions and weight, were not critical and easily designed for. To evaluate the concepts performance on the different criteria, they each had to be researched to the same extent for a fair comparison. Hence, additional *External Sourcing*, as in Section 5.1, was carried out through more benchmarking activities, mainly regarding COTS solutions, and further researching to what degree of modularity Saab should apply within their products. Lastly, expertise knowledge on costs, manufacturability, and other details was advised upon by Saab personnel. A screening process of the five generated concepts from Chapter 5 was performed in three screenings, that led to the selection of a final concept, see Figure 6.1.

## 6.1 First Screening

The *First Screening* of the *Concept Selection* was based on discussions with Saab employees and the results from the *Economic Analysis* in Section 2.3, as the main concerns of the thesis was to lower the costs of the PDS. Two concepts were eliminated from the *First Screening*: *Charlie* and *Echo*. The reasoning behind the eliminations are described in this section.

### 6.1.1 Elimination of Charlie

The generated concept *Charlie*, described in Section 5.2.3, has a 19-inch COTS chassis with 19-inch in-house developed units, see Table 5.2. The 19-inch units in *Charlie* are larger than the previous 19-inch COTS units used in the Modular PDS, so that more components could fit into one, and the total amount of units could decrease. By in-house developing the units, they would from the start be designed to carry the weight of the components within.

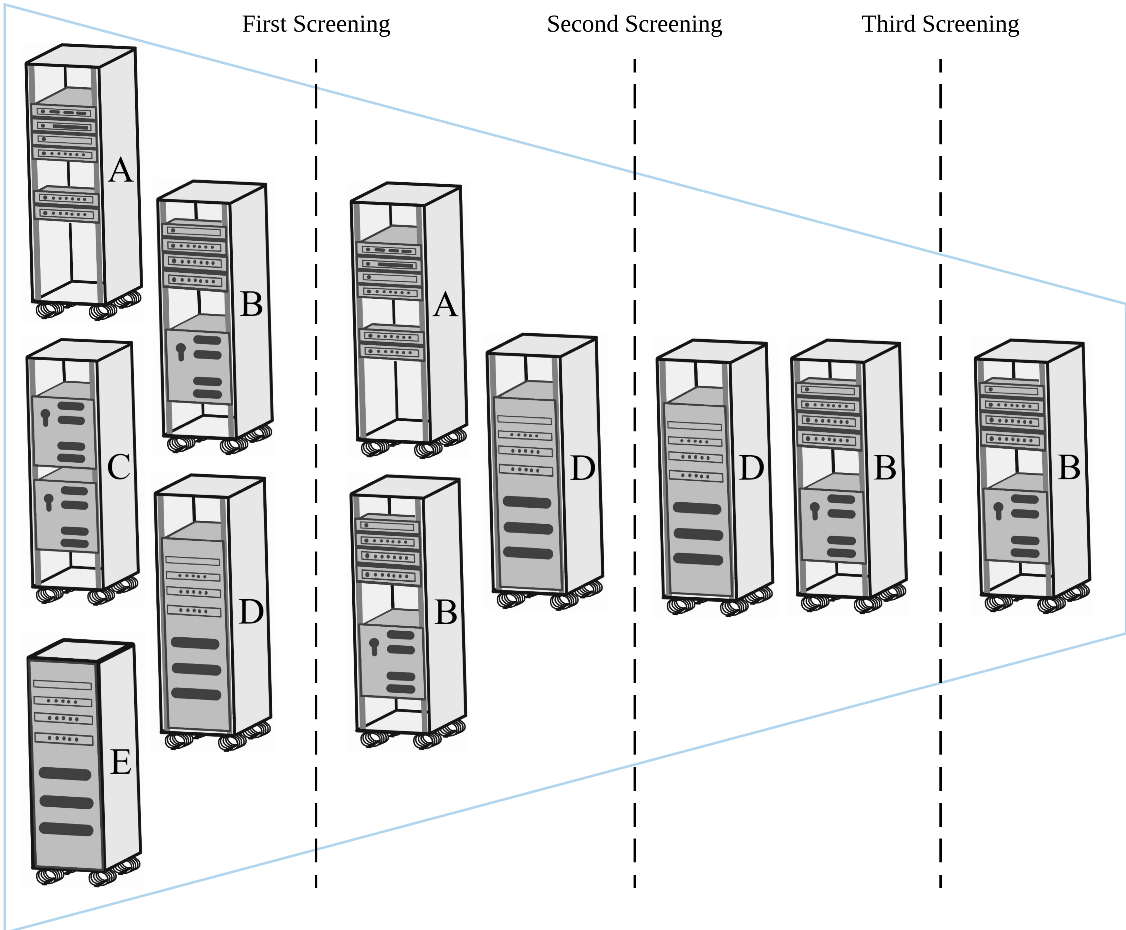


**Figure 6.1:** The screening process of the *Concept Selection*.

A result from the *Economic Analysis* showed that the mechanical parts of the PDS are a large contributory factor to the total production cost. The Modular PDS has more mechanical parts than the Integrated PDS, which increases production cost due to both material cost and assembly times. Therefore, concept *Delta* performed better than *Charlie*, as it only consists of one unit instead of several. The concept *Bravo*, like *Charlie*, has the 19-inch in-house developed unit, but is also complimented with purchased 19-inch COTS units to carry the simpler functions. The 19-inch in-house developed unit in *Bravo* was included as a single large unit that contains the more complex functions. Like *Delta*, *Bravo* has fewer in-house developed units than *Charlie*. *Bravo* does however have a larger number of units, but as the COTS units are purchased and decreases development costs, they are assumed not as expensive as *Charlie's* multiple in-house developed units. *Charlie* would be an improvement from the Modular PDS by from the beginning designing the units to hold the components without having to make later modifications. The units in *Charlie* would also have more room for its components, and would therefore decrease the number of units compared to the Modular PDS. However, *Charlie* is too similar to the Modular PDS for it to gain enough advantages from a re-design. This, together with the comparison to *Bravo* and *Delta*, the *Charlie* concept was eliminated.

### 6.1.2 Elimination of Echo

The generated concept *Echo*, described in Section 5.2.5, is the only one out of the concepts with an unique in-house developed chassis, see Table 5.2. The chassis is larger than the Integrated PDS's, to have room in the case of a capacity increase. From the *Economic Analysis*, the unique chassis of the Integrated PDS turned out to have a lower production cost than the 19-inch COTS chassis. This made the option of a unique chassis worth keeping. However, the *Economic Analysis* does not include the development cost of designing and verifying the chassis. The development cost is a one time cost that is later distributed over the amount of produced products. In the scope of this thesis, a restriction was made to focus on the production cost of the PDSs. Be that as it may, when choosing between the two different chassis types it was impossible to ignore the aspect of development cost, as it is essential for Saab when planning a project. The 19-inch COTS chassis is developed by a supplier and then sold to Saab. Meaning, there is no development cost, only production cost, which is why a higher production cost can be allowed when looking at the bigger picture.

To design and develop an unique chassis requires a lot of resources with following uncertainties regarding fulfilling the *Concept Requirements Specification*. To validate an unique chassis there is a testing process, which is costly, long, and thorough. If the unique chassis is not developed properly, the process can prolong and exceed the estimated development cost, resulting in a more expensive chassis than planned. The 19-inch COTS chassis is used in several of Saab's other systems and is therefore already generally validated and fulfills all of the requirements. Therefore, the 19-inch COTS chassis is the more reliable option. The *Echo* concept was hence eliminated due to its unique chassis. Its integrated interior can also be found in the concept *Delta*, which was validated in a later screening.

## 6.2 Second Screening

The *Second Screening* of the *Concept Selection* was based on discussions with Saab employees and the results from the *Benchmarking* in Section 5.1.2. One concept was eliminated from the screening: *Alpha*. The reasoning behind the elimination is described in this section.

### 6.2.1 Elimination of Alpha

The generated concept *Alpha*, described in Section 5.2.1, has a 19-inch COTS chassis with only 19-inch COTS units, see Table 5.2. It is the most innovative out of the five concepts, as it would be the biggest change and technological advancement for Saab. All of the development and most of the production of the units would be outsourced to suppliers. The outsourced units and the chassis would be delivered to Saab for final assembly and verification of a complete PDS before delivery. From the interviews with the System Designers, see Appendix A, they explained that they and other managers at Saab want to implement as much COTS products into their systems as possible. By outsourcing more, Saab would save resources and decrease complexity. As COTS products are a desirable solution to the managers at Saab, the *Alpha* concept was generated to explore and investigate the possibilities of its realization and how it would perform when compared to the other concepts. A meeting was held with a Saab employee who works with finding suitable COTS products, e.g. computers suited for the radar's control stations. He explained that in their make-or-buy decisions they initially check the availability of COTS. If none are to be found, they investigate the possibility of working with a supplier of COTS to create MOTS: Modified Off-The-Shelf products. This is more expensive, as the products have to comply with Saab's product requirements and have to be verified through extensive testing. If neither COTS nor MOTS are possibilities, then the only option is to instead develop it in-house.

Both COTS and MOTS carry a lot of risk as all supplier relationships do. As the Design Engineers stated in the interviews, see Appendix A, the risks of outsourcing relate to loss of control and late occurring costs in the production timeline. For this reason, products of high complexity that are Saab's core products are not outsourced. For simpler products, like a keyboard, its easy to make the decision to buy over make. The PDS is not a core product but carries more complexity than one would think, which makes the make-or-buy decision difficult. One such example is that the PDUs require control and monitoring customized per project. This means that the COTS alternative is eliminated. To apply MOTS would require a close relationship and development along with Saab employees to eliminate the risk of errors in production. This is a costly alternative and Saab could risk delaying the delivery of their system due to the risk of suppliers not prioritizing production of the units due to the low production volume. The last alternative, to develop such products in-house, is not an option for the *Alpha* concept being based on COTS.

The market, from which Saab can purchase products related to power distribution, is limited and is not yet offering products that fulfill all of the PDS's functions. The market does, however, provide some COTS that can possibly be used for the more simple functions of the PDS, such as pure power distribution. Therefore, the concept *Bravo* with its part-COTS, part-in-house structure, was not eliminated in the *Second Screening*, but further validated. Because of the limited offerings of power distribution units on the market and the many risks of having the PDS fully COTS-based, the *Alpha* concept was eliminated.

## 6.3 Third Screening

After the *First* and the *Second Screening* there remained two concepts: *Bravo* and *Delta*, who are described in Sections 5.2.2 and 5.2.4. The reasoning and process behind the *Third Screening* is described in the following sections. As discussed in the previous two screenings, *Bravo* and *Delta* performed better than the other three eliminated concepts in different aspects. Both concepts have a 19-inch chassis, which was argued to be superior to a unique chassis, see Section 6.1.2. Although, in the *Morphological matrix*, in Table 5.2, the units differ in the two concepts. *Bravo* has several 19-inch COTS units for the simpler functions, and a 19-inch in-house developed unit with the more complex functions. *Delta*, on the other hand, only has one integrated in-house developed unit where all components share a common space.

### 6.3.1 Equating Units

From further discussions with Saab employees, the integrated interior of the Integrated PDS was argued to be better than the one of the 19-inch units found in the Modular PDS. The structure of the Integrated PDS, described and shown in Section 2.1.1, is vertical. This means that in assembly or service, the personnel only have to work from one direction when entering and handling the PDS. This allows for better reachability, visibility, and in turn saves time and money. The structure of the 19-inch units, described in Section 2.1.2, results in the personnel to work from three different directions. The switches are placed in the front, cables enter and exit from the back, and the components are assembled and reached during service from above. In some cases, as for the PDU3 in Figure 2.4, the unit also has a middle section that has to be removed if a component placed underneath it has to be replaced. Additionally, due to the weight of the unit, and to be able to reach the cabling in the back, some of the units require rail mounting, cable arms, and reinforcements, which adds to the production cost.

With the superior vertical interior structure of the Integrated PDS, *Bravo's* 19-inch in-house unit was re-generated to have the same structure. Thereby, *Bravo's* in-house unit was equated to the unit in *Delta*. The two concepts then only differed in the application of COTS.

### 6.3.2 Performance Comparison

The two remaining concepts were compared on the *Performance Parameters* in Table 6.1, found in Section 3.2 that laid the basis for the *Concept Requirements Specification* in Appendix B. *Delta* was set as the reference, and *Bravo* was hence evaluated in reference to how *Delta* performed: worse than (-), better than (+), or equally as well (0). The *Performance Parameters* were divided into two sections. The top section of the parameters were deemed to affect the cost the most and were hence of greater importance. The bottom parameters also affect the costs, but not to the same extent.

As shown in Table 6.1, the two concepts performed equally in total, both in the top and bottom parameters. However, because of *Bravo's* COTS units, the evaluation was not as straight forward, due to the challenges and uncertainties related to outsourcing. *Bravo* and *Delta* performed equally on six of the *Performance Parameters*, i.e. *Intuitiveness*, *Reachability*, *Size*, *Spaciousness*, *Uniformity*, and *Visibility*. This is due to the equated large in-house developed unit and the 19-inch chassis that can be found in both concepts. *Bravo* performed better than *Delta* in regards to *Development Cost*, but worse when looking at the *Production Cost*. As previously discussed in Section 6.2.1, this conclusion was drawn because of *Bravo's* application

**Table 6.1:** A comparison of how *Bravo* and *Delta* perform on different parameters.

| **Performance Comparison** | | |
|---|---|---|
| **Performance Parameters** | **Delta** | **Bravo** |
| Development Cost (DC) | 0 | + |
| Production Cost (PC) | 0 | - |
| Cabling (PC) | 0 | - |
| Materials (PC) | 0 | - |
| Flexibility (DC) | 0 | + |
| Standardization (DC) | 0 | + |
| Intuitiveness | 0 | 0 |
| Reachability | 0 | 0 |
| Serviceability | 0 | + |
| Size | 0 | 0 |
| Spaciousness | 0 | 0 |
| Uniformity (Design) | 0 | 0 |
| Visibility | 0 | 0 |
| Weight | 0 | - |
| **SUM** | **0** | **0** |

of COTS units. The simpler functions are developed and produced by a supplier, which saves Saab development resources. Although, *Bravo* runs the risk of increasing the production cost and involves outsourcing risks. When adding COTS units to the PDS, both *Materials* and *Cabling* increases, which is why *Bravo* performed worse than *Delta*. Similarly to the Modular PDS, the COTS units would increase internal cabling between the units, which is a large cost contributor. Nevertheless, the COTS units in Bravo leads to increased *Flexibility* and *Standardization* of the PDS. If the capacity were to increase in a project, additional COTS could easily be stacked to cover this need without further development cost. The functions are more separated in *Bravo*, as some are carried by the individual COTS units, compared to *Delta's* single unit. Therefore, *Bravo* performed better on *Serviceability* than *Delta*. However, due to the larger amount of mechanical parts, as each COTS unit has its own chassis, the *Weight* was considered to be marginally larger than *Delta's*.

The evaluation and screening of the two remaining concepts based on the *Performance Parameters* was not as fruitful as it was sought out to be. This was partly due to their physical resemblance and the uncertainties regarding COTS units. The risks and challenges of COTS units was then considered to be the pinnacle aspects of the *Third Screening*.

### 6.3.3 COTS Trade-offs

The aspects to take into account when considering COTS products have been discussed many times over in the preceding sections. The COTS trade-offs were between the benefits: *Development Cost*, *Flexibility*, *Standardization*, *Size* and *Uniformity*, and the drawbacks: *Production Cost*, *Cabling*, *Materials*, *Weight* and the risks. General uncertainties regarded which suppliers to use, namely what countries they originate from and whether they comply with export certifications, e.g. EN 9100 (SIS, 2018). It could also regard working with new suppliers, whom have to adjust their, or tier-supplier's, manufacturing or other processes which have to be certified and the products have to be tested. According to one strategic purchaser at Saab, these are the reasons why it might be valuable to work with geographically closer suppliers, as during the beginning of the relationship there are a lot of establishing work to do. During the *Benchmarking of COTS*, see Section 5.1.2, it showed that the majority of the suppliers were from the USA. With that said, American suppliers have a wider selection of COTS products, already military use certified, which might be worth the risks as it could eliminate costs related to modifying their existing offerings, enabling pure COTS products.

To visualize the technology advancement for AC and DC units, an S-curve was created based on the learnings from both the benchmarking and from the many discussions with Saab employees with power and/or COTS expertise, see Figure 6.2. An S-curve shows how products advance during a product lifetime. As it is *Emerging*, the technology itself is limited and develops slowly. When the technology is at *Take-off*, it has met a brake through, which leads to rapid advancement. As it reaches *Maturity* it becomes a 'dominant design' which is the market's leading technology. Finally, as the technology has reached *Saturation*, the performance limit has been reached and development focus is shifted towards optimizing process efficiency to maintain or gain competitiveness. The s-curve was first introduced by Foster (1986).

As Figure 6.2 shows, the identified AC units were not as advanced as the DC units, even though the *Benchmarking of COTS* in Section 5.1.2 showed a supply of just as many DC as AC (non-restricted) PDU COTS units. The choice of placing AC units in the *Take-off* section was based on them not being as standardized in their offerings, when comparing to DC units. The offerings of DC units being more standardized

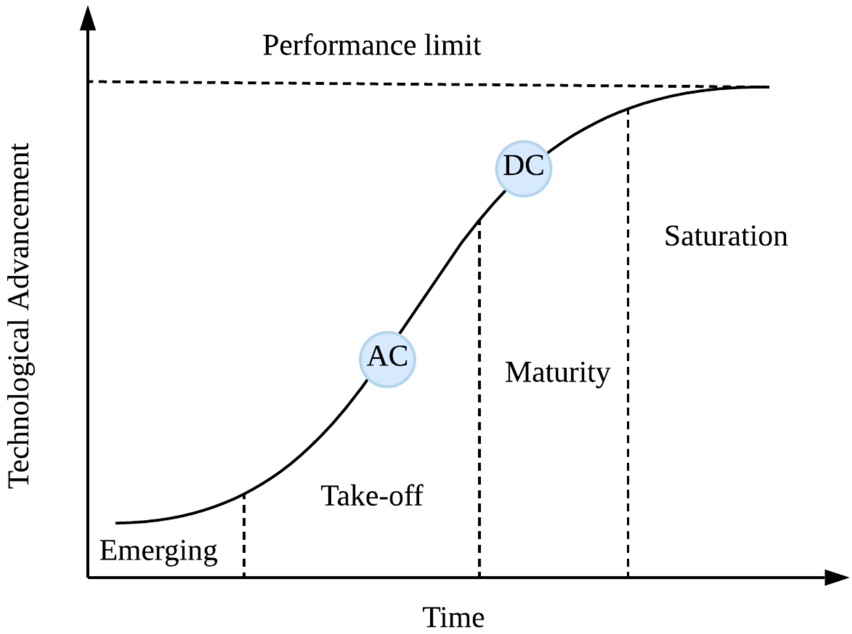


**Figure 6.2:** S-curve placement of AC and DC COTS PDUs.

placed them in the *Maturity* section. As for the decision-making regarding including COTS or not, the AC units might be more expensive than the DC units as they have not yet reached the mature state. As technology advances and perhaps more market segments require digital AC COTS units, they might advance to a mature state as well, leading to more competitive markets and prices.

### 6.3.4 Decision

Even though there are uncertainties and risks of applying COTS units, Saab's management and engineers strongly believe that COTS units lower the total costs mainly by minimizing the development cost. The benefits of a flexible design is motivated because of the demand for customization in each project and short deadlines. As discussed in the *Benchmarking of COTS* in Section 5.1.2, it was presented that the power distribution function of the PDS could be divided into one controlling and monitoring unit and additional units for pure capacity increase. The controlling and monitoring unit has to be a modified COTS, a MOTS, or an in-house unit, and the additional ones could be pure COTS units. MOTS and in-house developed 19-inch units were found a non-suitable option as the modifications per project would be too many, which would increase costs. The concept would resemble the Modular PDS, or even the *Alpha* concept which were both deemed too expensive to proceed with. Therefore, it was decided to implement basic, pure COTS to carry the simpler functions, while the customization would be kept in the in-house developed unit. These types of COTS units exist on the market and are available for both AC and DC, as found in the *Benchmarking of COTS* in Section 5.1.2.

The final decision was made to select *Bravo* as the concept to further develop. There are matured size optimized COTS units on the market that have the possibility to lower the development cost and will increase the flexibility of the PDS. The option of COTS PDUs has, therefore, been considered a viable solution. To establish exactly what supplier and product to use can not be decided in this thesis, but will have to be decided by the Quality and Purchasing departments at Saab, as it requires great experience and insight. If, however, the suppliers and the products have been identified, and the cost and risks turn out to be too high, then the *Delta* alternative is a close-to-comparative concept as shown in Table 6.1. The integrated unit in *Delta* is simply a scale-up of the integrated unit of *Bravo*. The unit has to be verified no matter the choice of concept and hence there are as much costs related to both development and testing of that unit.

# 7

# Development of the Selected Concept

The selected concept to further develop was the concept *Bravo*. In Chapter 5, the concept was generated on a general system level. It became more defined through the screening process when compared to the other concepts in Chapter 6. Before verifying the product concept, *Bravo* had to be further developed. When realizing the *Bravo* concept, using Creo (PTC, 2009), decisions were made in close contact with Saab employees. It was decided to keep the level of detail general, as the true value for Saab lay within the analysis' and concept of the next generation PDS.

## 7.1 Internal Function Carriers

The internal function carriers are discussed in the following section. The transformer found in the existing PDSs is discussed and removed for the re-design of the PDS. The functions are advised to be separated into base and unique requirements to enable standardization, as a maximum requirement could not be defined.

### 7.1.1 Removal of the Transformer

In both the Integrated and the Modular PDS, there is a large transformer that converts the 400 VAC to 200 VAC, see the *Functions Analysis* in Section 2.2. The transformer weighs about 20 kg and resulted in the PDSs having to be reinforced with extra beams and fixtures to carry it's heavy weight. The design engineers explained that the 200 VAC created by the transformer only provides current to a special fan placed inside of the radar. If the fan were to be exchanged to one that requires 400 or 440 VAC, the transformer could be removed.

In the *Economic Analysis* in Section 2.3, the mechanical parts of the PDS were concluded to be the main cost drivers. By replacing the fan and removing the transformer, the PDS would require less mechanical reinforcement and thereby save production costs. Additionally, removing the transformer would save space within the PDS for other components, reduce the total weight of the PDS, eliminate the cost of the transformer, and create a more spacious interior, which would ease production and serviceability. However, if the fan were to be replaced, the new fan would have to be validated to ensure fulfillment of the requirements, which could become costly. Although, when choosing between validating a new fan, which is a one time cost, or keeping the transformer for every produced PDS, the best option would be the former in a long-term perspective. The design engineers are aware of the challenges associated with the transformer and their ambition is to bring the issue further to the management level, so that the transformer can be removed. The decision of removing the transformer and replacing the fan has not been considered crucial, which is why it has been kept. For these reasons, the transformer was not included in the *Bravo* PDS.

### 7.1.2 Dividing Functions

Saab's radar systems are complex, unique, and highly technological, and buying a radar system is a large investment for Saab's customers. That is why Saab develop their systems to fit every customer's specific requirements. It is therefore challenging for Saab to create a product architecture for their products to adapt to every customer, while having a low production volume. During the thesis work, many of Saab's personnel have been asked if they could define a maximum capacity limit for the PDS, so that it could be designed thereafter. It turned out to be the million dollar question. Several attempts were made but without any success. For example, a couple design engineers developed a 19-inch back plate for a PDU that had a maximum amount of outlets. The idea was that the plate would stay the same for all PDUs and eventual unused outlets would be plugged depending on the individual project's needs. However, the plate was soon outdated as the requirements of the different projects were too diverse.

The maximum capacity is in a sense undefinable, because whatever the customers want, Saab will try their best to provide it. Therefore, it would be beneficial to instead define a base-requirement that comprises all of the requirements that are the same for all projects. The base-requirements would enable standardization and commonality of parts, which would save development and production costs. For every new project, the development work would then only be focused on the unique requirements and how they are connected to the base-offering. This is first and foremost an electrical engineering issue that requires design engineers with such capabilities. Due to the focus on the mechanical aspects of the PDS, the limitation was made to not include electrical components and their design.

## 7.2 Mechanical Design of the Unit

In the *Third Screening* of the *Concept Selection* in Section 6.3.1, the 19-inch in-house developed unit in *Bravo* was equated with *Delta's* and was argued to have the same vertical structure as in the Integrated PDS. The structure of the PDU unit of the Integrated PDS is described and displayed in Section 2.1.1 and illustrated in Figure 7.1. The vertical structure is beneficial during production and service, as the components are more visible and reachable from one direction. In short, the structure of the Integrated PDS has two layers: a front plate (A) where the fuses and switches are mounted, and a back plate (B) where the components are placed. Between the two layers there is a distancing fixture that hinges the front layer and enables it to be opened like a door. The two layers are protected by a metal housing that shields the user from involuntarily interfering with the components and cables. The structure divides the components and fuses into separate layers. When analyzing the Modular PDS it was found that the fuses in each PDU determined the height of the units, e.g. as PDU1 shows in Figure 2.5. Therefore, by placing the fuses and components on different layers, the unit can be better size optimized, which is why the structure of the Integrated PDS was kept for the unit in *Bravo*.

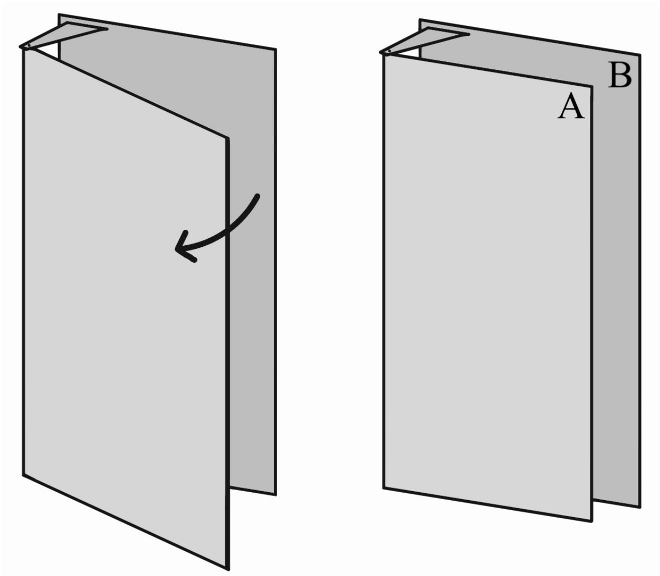


**Figure 7.1:** An illustration of the unit with its vertical structure, where the front plate (A) is hinged to the back plate (B) and opens like a door.

A concept generation was performed to challenge the existing way of how the two layers were designed and alternative ways of what the structure could look like were explored, see Figure 7.2. The front plate is hinged and opens like a door, where the cabling between the two layers are drawn on the same side as the hinge. Alternative ways of opening the front layer were therefore discussed. If the front layer were to open with the hinges placed at the bottom and opened from the top (like a dishwasher), the load would be centered at the top, making the unit vulnerable for large impacts and vibrations. Another option would be to have the hinges placed at the top of the front layer and opened through lifting it. However, during assembly and service the front layer would risk closing on the personnel. Furthermore, the layers could be mounted like sliding doors where the standing layers could be pulled out from the chassis. Although, having the layers extend out from the chassis would require longer cabling and heavy counter-weights, which would be very costly. Even though the effort was made to find a potentially improved solution, the current door solution was found to be the best one.

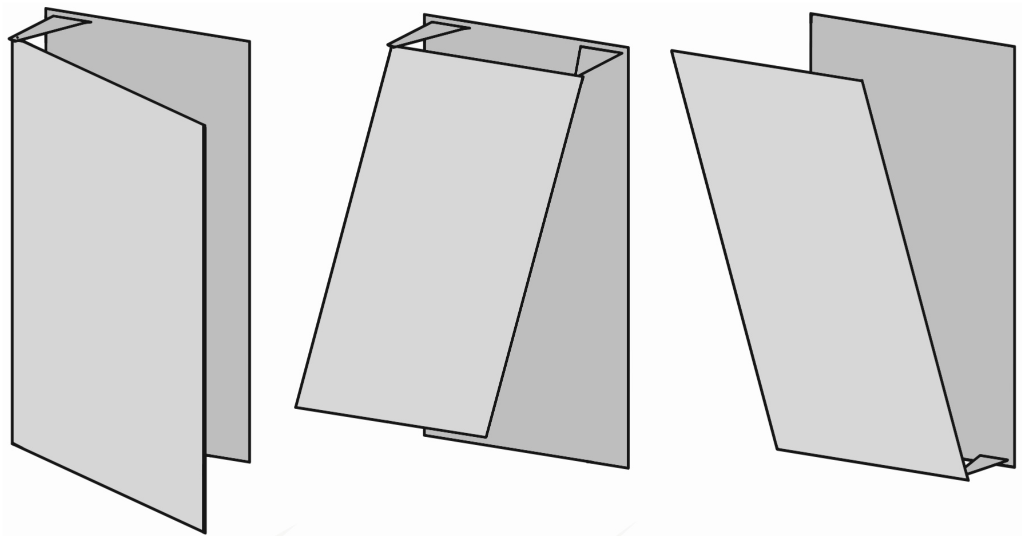

**Figure 7.2:** An illustration of some of the generated structure concepts.

The Integrated PDSs switches and fuses are mounted on holders on the front door, which can each be altered to the project's requirements. The same ones are used in the Modular PDS. In their modular nature, they are fairly flexible and were deemed good enough to keep in the next generation's design. However, during the thesis Saab employees advocated to look deeper into other types of fuses and switches as they are very large and heavy and, as stated, limit the mechanical design. Investigating individual components was off the thesis's scope, and alternative solutions were hence not assessed. The front plate in the Integrated PDS's PDU has four sections for holding the fuses. However, as the Integrated PDS also includes the components of the PSI, *Bravo's* unit was therefore extended in height to have a total of five fuse sections to ensure enough space. Although, depending on the requirements of future projects and the amount of required components, the unit could potentially be smaller. Additionally, the door of the chassis is hinged on the left side, while the unit in the Integrated PDS was hinged on the right side. A decision was made to also hinge *Bravo's* unit to the left, so that both unit and chassis open on the same side to create more space for the user during service.

## 7.3 Mechanical Design of the Chassis

The chassis of *Bravo* is a 19-inch MOTS chassis, which is used in the Modular PDS along with other products within Saab's offerings. As previously mentioned in Section 6.1.2, the chassis was already validated and fulfills the requirements in the *Concept Requirement Specification*, see Appendix B. The chassis has a standardized interior mounting rack with holes that enables units with the same 19-inch standard to be mounted at an optional height within the chassis. The PCP is placed on the door of the chassis, but does not interfere with the units placed within the rack. This means that the placement of the units in the rack does not have to take the PCP into consideration.

The in-house developed unit contains all of the more complex and project specific functions of the PDS. Due to its weight was it placed at the bottom the chassis. Under the bottom distancing fixture between the layers, there is a fixture that was altered to rest on the bottom of the chassis. The fixture was made higher than the one in the Integrated PDS, so that the door of the unit could be opened when placed within the Modular PDS's chassis. The unit was fastened with beams and fixtures on the sides of the rack inside of the chassis. As *Bravo's* chassis is the same as the Modular PDSs, the ECI and contact plate at the top of the chassis were kept. By having the contact plate at the top of the chassis, the cables do not interfere with its surroundings if other systems were to be placed next to the PDS. Additionally, the personnel at Saab explained that in the machine room of the ship, the cables travel from the ceiling. Therefore, the placement of the contact plate was concluded to be carried over to *Bravo*.

## 7.4 Implementation of COTS

As discussed in Section 6.3.4, it is up to the Purchasing and Quality departments at Saab to make assessments of the benchmarked COTS units and suppliers. Due to this, the physical design and interfaces of the rack and COTS units could not be fully designed. The identified units have two different appearances. One alternative is that they are vertically mounted in a sliding cassette design, where they have contacts at the back, which they dock in to when pushed in place. In the second design, they are horizontally mounted and fastened with screws at the front rails of the rack. At the back of the units there are commonly cable bushings instead.

According to the Service Lead, see interview answers in Appendix A, cable bushings are preferred when the unit is rarely modified and does not commonly require service. Contrarily, contacts are more preferable when the unit is commonly modified. The COTS PDUs are not supposed to be controlled or monitored, but rather act as a power strip to the base-PDU. For this reason, horizontally mounted units have been included in the design to visualize the use of space. These units are however not specific COTS, nor should they be perceived as a recommendation in regards to which supplier or product to go with.

# 8

# Verify Product Concept

The following chapter is a merge of two of the steps of Ulrich and Eppinger (2012) development process: *Test Product Concept* and *Set Final Specifications*, named *Verify Product Concept*. As the *Concept Requirements Specification*, see Appendix B, requires subjective verification to a large extent, continuous discussions with Saab personnel were kept during development of *Bravo*. Hence, the *Performance Parameters* are discussed on those accounts. Criteria were argued to either be verified and fulfilled (✓), or not (✗), or only partly verified and/or fulfilled (∼). The *Concept Requirements Specification* also includes external criteria on climatic and mechanic requirements which are measurable and could be verified. However, due to the thesis limitation delivering a concept, rather than a complete product, these criteria were not verified. Input from both mechanical and electrical design engineers was helpful during the development of *Bravo* as their expert knowledge on working with the systems guided design decisions to feasible solutions.

## 8.1 Economic Assessment of Bravo

As the concept *Bravo* was not developed in detail, but rather on a general level, an economic assessment of the development and production costs could only be estimated using the same documentation as was used to perform the *Economic Analysis* in Section 2.3. Table 8.1, is an extraction of the *Concept Requirements Specification*. See the full specification in Appendix B.

As the Modular PDS was more expensive than the Integrated PDS, both in terms of development and production costs, it was set as the maximum requirement. However, as the cost was central for the development effort, the lowest possible costs were aimed for throughout. Note in Table 8.1 how criteria 3.1.1, 3.1.2, 3.2.1 and 3.2.2 were added to their preceding requirement, 3.1 and 3.2. The low level of detail in *Bravo* did not allow for such narrow assessment. They were instead included within their respective top-level requirement. The *Development Cost* was not possible to calculate but could instead be estimated to be larger or smaller than the Modular PDSs. However, the *Production Cost* could be calculated through a rough estimation using the same documentation used for the *Economic Analysis* in Section 2.3 as the *Bravo* concept re-uses most of the Integrated and Modular PDSs' parts.

**Table 8.1:** Extraction of costs criteria from the Concept Requirements Specification.

| Concept Requirements Specification | | | | | |
|---|---|---|---|---|---|
| **Category** | **Criteria** | **Target Value** | **Verification Method** | **N/R** | **Verified?** |
| **3. Cost** | | | | | |
| | 3.1 Development Cost (DC), SEK | $\leq$ Modular PDS | Cost estimation | R | ✓ |
| | 3.1.1 Flexibility (DC) | | | | |
| | 3.1.2 Standardization (DC) | | | | |
| | 3.2 Production Cost (PC), SEK | $\leq$ Modular PDS | Cost estimation | R | ✓ |
| | 3.2.1 Cabling (PC) | | | | |
| | 3.2.2 Materials (PC) | | | | |

### 8.1.1 Development Cost

It was discussed during the *Concept Selection* in Chapter 6, in the *Third Screening*, that the *Bravo* concept has minimal *Development Costs* related to each project. The costs for purchasing COTS PDU units were added instead of re-designing a larger unit for every project. This modularity hence increases the *Flexibility* during development. The 19-inch standard COTS units also maximizes the level of *Standardization*. Saab's first development of *Bravo* will carry more development cost to finalize the design concept, while future projects carry less development cost.

As the unit in *Bravo* is similar to the unit in the Integrated PDS, but includes the COTS units, the development cost per project should not be higher than for the Integrated PDS either. The COTS units are assumed to only add to the *Production Cost*. For these reasons, criterion 3.1, including criteria 3.1.1 and 3.1.2, was assumed fulfilled.

### 8.1.2 Production Cost

*Bravo's Production Cost* ought to be lower than the Modular PDSs as it's integrated unit is much simpler and faster to produce in comparison to having several individual units, according to the industrial engineers. See Appendix A for the interviewees' statements. The COTS units could entail an increase in the amount of *Cabling* compared to the Integrated PDS, but should require less than the Modular PDS. As discussed during the *Economic Analysis* and the interviews, *Cabling* is one of the greatest cost-drivers during production and focus should lie on minimizing that cost. Lastly, *Bravo* should decrease the amount of *Materials* in comparison to the Modular PDS due to fewer units. The COTS units do increase the amount of *Material*, but the idea was that the cost would in total decrease when weighed against the *Production Cost*.

As was explained in the *Economic Analysis* in Section 2.3, the production costs in Saab's PLM system includes: purchased goods, production hours, currencies, materials markup and logistics. The production hours can also be assessed separately but the costs shown in the system are bundled into one and does not show which cost stands for what amount. It was hence difficult to know which level within the structure that included what type of production hours. As the parts in *Bravo* include parts from both the Integrated and the Modular PDS, there is a risk that too many production hours were included, or that some crucial amount was missed. The concept of levels was also explained in the *Economic Analysis*. Level 0 is the top-level assembly and could include some minor mechanical parts such as screws and washers. Level 1, in *Bravo's* case, includes the 19-inch chassis, the integrated unit, mechanical parts for integrating the unit into the chassis rack and the potential COTS units. Other levels would be components and parts of each level. Table 8.2 presents the estimated costs of *Bravo* in percentages of its entire chassis and mechanical parts' total production cost. Note that there are two alternative results, which is due to the *Unit* being calculated in two different ways, which will be explained.

**Table 8.2:** Estimated production costs of *Bravo's* chassis and mechanical parts.

| **Estimated PC of *Bravo's* chassis and mechanical parts** | | |
|---|---|---|
| | **% of total PC** | |
| **Unit** | **Alt. 1** | **Alt. 2** |
| PDS | 14,6 | 10,4 |
| Chassis | 32,2 | 22,7 |
| Unit | 51,2 | 65,5 |
| Mechanical parts | 2,0 | 1,4 |
| COTS PDU(s) | X | X |
| **SUM** | **100+X** | **100+X** |

Level 0 is the top-level assembly, where the units are mounted within the chassis. This level is named *PDS*. As Level 0 in the Modular PDS includes hours for assembling four different units, this cost was divided by four in *Bravo's* case. Costs for assembling the required amount of COTS units should be added in the cost estimation prior to each project start-up. As the 19-inch chassis design is the same as for the Modular PDS, the *Chassis* cost was simply copied. The cost for the *Unit* was retrieved by using the costs for the PDU of the Integrated PDS. The *Unit* is larger than the PDU but the added materials cost was assumed minimal and the operations made to the different parts would cost approximately the same. One concrete part was the fifth holder for the fuses and switches which was added when increasing the height. There were two options to estimating the unit's cost. Alternative 1 was to sum up the costs for the production hours for the entire PDU (including the outer chassis' production hour costs) and the costs for the individual parts within the unit. The issues related to this alternative was that smaller components would be neglected due to the low level of detail in the model. Alternative 2 was to take the entire PDU unit of the Integrated PDS and remove costs for the outer chassis, electronics, contact plates and fixtures relating to the heavy transformer, which was decided to be removed, see Section 7. Issues related to this alternative was that far too many smaller components would be included along with their assembly times. The two alternatives differed a lot more than expected and it was found in the second alternative that several small components such as hinges and washers were oddly expensive. When looking at the production hours only, the assembly cost of the entire Integrated PDS's PDU represented about 50 % of the total production hours spent on the PDS. It was found that most of the production cost related to cabling and assembling electrical components were placed in the assembly level of the entire unit and not in the beneath level, where the electrical components are placed. Even if this cost does not represent hours spent on the mechanical parts, it was still included as the results would otherwise be biased when comparing *Bravo* to the Integrated PDS. The same argument goes for the Modular PDS as well, as its assembly costs might, too, be misplaced in the PLM system. The *COTS PDU*s were set as unknown ($X$), as there was no way of knowing what such products would cost or how many would be required. When developing the first *Bravo* concept, this would have to be added. Lastly, minimal amount of *Integration parts* were added to the design, i.e. the four beams and four fixtures required for fastening the unit.

In Table 8.3, *Bravo's* chassis and mechanical costs are compared to the Integrated and Modular PDSs respectively. For continuity reasons, the costs are expressed in percentages of Integrated PDSs estimated production costs. Note that the *Bravo* concept's two alternative ways of calculating the unit's cost are displayed but that neither include costs for the COTS PDU units.

**Table 8.3:** Estimated production costs of Integrated, Modular and Bravo PDSs chassis and mechanical parts expressed in percent of the Integrated PDS.

| **Estimated PC of chassis and mechanical parts** | |
|---|---|
| | **% of Integrated PDS** |
| **Integrated PDS** | 100,0 |
| **Modular PDS** | 165,6 |
| **Bravo PDS** | Alt. 1: 94,9*<br>Alt. 2: 134,3* |

* Excluding costs for potential COTS PDU units

There were a lot of insecurities regarding the existing costs in the PLM system, as discussed about the obscure costs of small mechanical parts. There were also questions on how the system structured the production hours on the different levels. The real cost of the *Bravo* PDS ought to stay within the scope of Alternative 1 and 2. Naturally, the aim should be to develop a PDS as close to Alternative 1 as possible, but Alternative 2 was still cheaper than the Modular PDS's estimated production cost, which was the target value, and hence *Bravo* fulfills the *Production Cost* criterion 3.2, including criteria 3.2.1 and 3.2.2.

## 8.2 Assessment of Bravo's Performance Parameters

The following section includes an assessment of how well the final concept performs on the *Performance Parameters* extracted from the interviewing process, see Chapter 3. The *Performance Parameters* were divided into *Usability Parameters* and *Design Parameters*, and were assessed separately.

### 8.2.1 Usability Parameters Assessment

Table 8.4 is an extraction of the *Usability* criteria from the *Concept Requirements Specification* found in Appendix B. These criteria in the *Concept Requirements Specification* either have the *Target Value* of performing better than and equally as good as the PDS which performed best. The comparison between the Integrated and the Modular PDS was made in Chapter 3: *Identify Customer Needs*. The *Verification Method* was set to be a *Subjective Assessment* as it was not possible to set measurable target values. Also, the criteria were set as needs, meaning they were not crucial to the design choices as they did not directly affect the costs.

**Table 8.4:** Extraction of usability criteria from the Concept Requirements Specification.

| Concept Requirements Specification | | | | | |
|---|---|---|---|---|---|
| **Category** | **Criteria** | **Target Value** | **Verification Method** | **N/R** | **Verified?** |
| **4. Usability** | | | | | |
| | 4.1 Intuitiveness | ≥ Modular PDS | Subjective assessment | N | ∼ |
| | 4.2 Reachability | ≥ Integrated PDS | Subjective assessment | N | ✓ |
| | 4.3 Serviceability | ≥ Modular PDS | Subjective assessment | N | ✓ |
| | 4.4 Spaciousness | ≥ Integrated PDS | Subjective assessment | N | ✓ |
| | 4.5 Uniformity | ≥ Modular PDS | Subjective assessment | N | ✓ |
| | 4.6 Visibility | ≥ Integrated PDS | Subjective assessment | N | ✓ |

The unit in *Bravo* has good *Reachability*, criterion 4.2, due to the door-opening solution of the Integrated PDSs PDU unit. The same goes for the *Spaciousness*, criterion 4.4, especially as the COTS units have removed functions from the unit, along with the 19-inch chassis being much larger than the Integrated PDSs chassis. The unit and dividing of simple functions into COTS PDUs should also increase the

*Visibility*, criterion 4.6. Lastly, the standardized 19-inch chassis was the reason for the Modular PDSs being valued high on *Uniformity*, criterion 4.5, which was re-used in *Bravo*. Criteria 4.2, 4.4, 4.5 and 4.6 were hence deemed fulfilled.

The *Intuitiveness* and *Serviceability* criteria, 4.1 and 4.3, requires some more discussion. The unit being opened like a door along with the COTS PDUs being small and light weight, should enable easy access and thereby also service. However, the Modular PDS's division of its units by function increases its *Intuitiveness*. If there were to be any malfunction, it might be easier to understand what functions are affected at first glance. Common malfunction is communicated through the fuses so this could be designed to be improved in *Bravo* through sectioning the unit into functions, and that the fuses might reflect this sectioning. Criterion 4.1, *Intuitiveness*, could hence be fulfilled but this depends on component design and placement, which was out of the thesis' scope. As *Serviceability* is also closely related to *Reachability*, which has been improved through the unit, criterion 4.3 should be fulfilled.

### 8.2.2 Design Parameters Assessment

The *Design* criteria only regard the *Dimensions* and the *Weight* of the entire outer chassis of the PDS, see Table 8.5 for the extraction of those from the *Concept Requirements Specification*, found in full in Appendix B.

**Table 8.5:** Extraction of design criteria from the Concept Requirements Specification.

| Concept Requirements Specification | | | | | |
|---|---|---|---|---|---|
| **Category** | **Criteria** | **Target Value** | **Verification Method** | **N/R** | **Verified?** |
| **5. Design** | | | | | |
| | 5.1 Dimensions | $\leq$ Modular PDS | Measure CAD-model | R | ✓ |
| | 5.2 Weight, W | $\leq$ Modular PDS | Measure CAD-model | R | ✓ |

The 19-inch chassis of the Modular PDS is much larger than the Integrated PDS's chassis. While there are few restrictions on dimensions and weight for naval application PDSs, the Modular PDS was in retrospect deemed the largest it ought to be. As *Bravo* uses the same chassis, the outer dimensions are the same. This does fulfill the set requirement, but late during the thesis, it surfaced that it would be preferable for the new-generation PDS to be both lower and, more importantly, lighter than the Modular PDS. As *Bravo* has fewer units and hence both less mechanical parts and cabling than in the Modular PDS, the weight ought to be lower. As the 19-inch chassis follows the same standard U height as the units did in the Modular PDS, it is possible to order a lower one. The width and depth remains. The limiting factor would then be the dimensions and amount of required COTS PDUs. When realizing the PDS in future projects, and the capacity does not require such a large chassis, then one of fewer U height should be applied instead. This should also positively affect the weight.

The model's weight was possible to retain from Creo (PTC, 2009), but the results were not plausible. *Bravo's* weight was only 30 kgs lighter than the Modular PDSs total weight, when it included components. Either the Modular PDS's or *Bravo's* model's weights were estimated wrong. It was also not possible to extract the mechanical and chassis weights only from the Modular PDS. This should be investigated if pursuing and realizing *Bravo* in future projects. The requirements are, however, due to the arguments stated previously, fulfilled.

# 9

# Final Concept

The final *Bravo* concept of the next generation sea-based PDS is shown in Figure 9.1. It is a hybrid solution in a standardized 19-inch chassis with an integrated in-house developed unit and stackable COTS PDUs. It was designed and modeled in Creo (PTC, 2009) to visualize it's structure. The model of the Modular PDS was imported to act as a base for the *Bravo* concept, as they have the same chassis. The motivations behind the design choices were explained in Chapter 7.

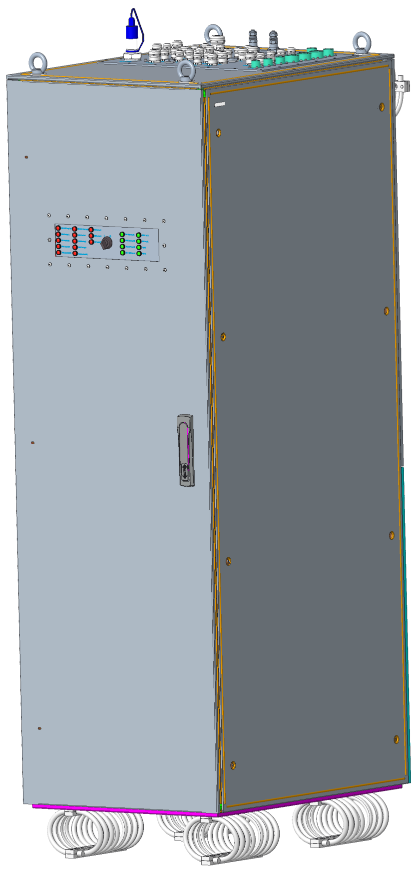

**Figure 9.1:** The final *Bravo* concept from the front showing the outer chassis.

The chassis is purchased from a supplier and is already validated to fulfill the climatic and mechanic requirements. To withstand large vibrations and shocks, the chassis is provided with four dampers at the bottom and two at the back, which are bolted to the floor and wall of the machine room. The chassis has four metal rings at the top to lift the PDS during installation. A contact plate where all cabling enters and exits the PDS is placed at the top of the chassis. By having the contact plate at the top, the cables are centralized to avoid disturbing its surroundings when installed. A PCP is placed on the front door, which has a main power switch and communicates the status of the PDS to the user through positive and negative diodes.

The front door opens by turning the handle and swinging the hinge mounted door open. Figures 9.2 and 9.3 show the views of the PDS with its front, side and back sections removed, exposing the interior of the PDS. The chassis has a 19-inch standard rack that allows mounting of units of the same standard. Same as for the Modular PDS, the ECI is placed in the top of the rack, containing filters and lightning protection which prohibits excessive current from entering the PDS. The ECI is protected by a metal plate that is fastened in the rack using additional beams on the sides and back.

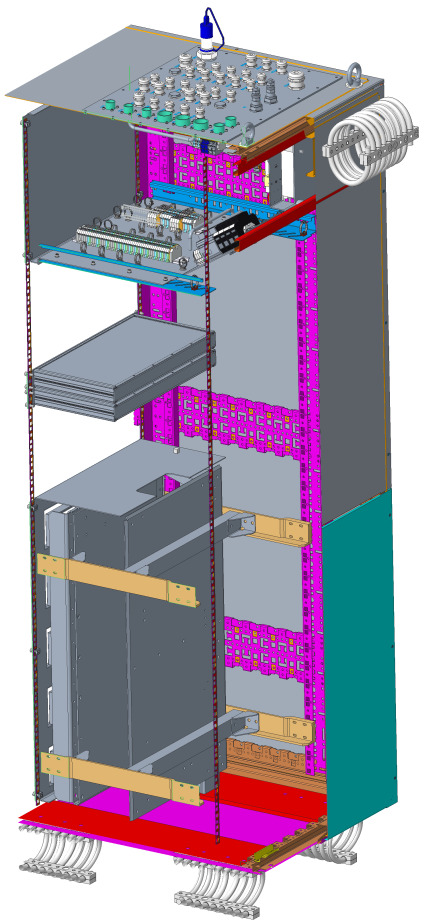

**Figure 9.2:** The final *Bravo* concept shown from the back with front, side, and back sections removed.

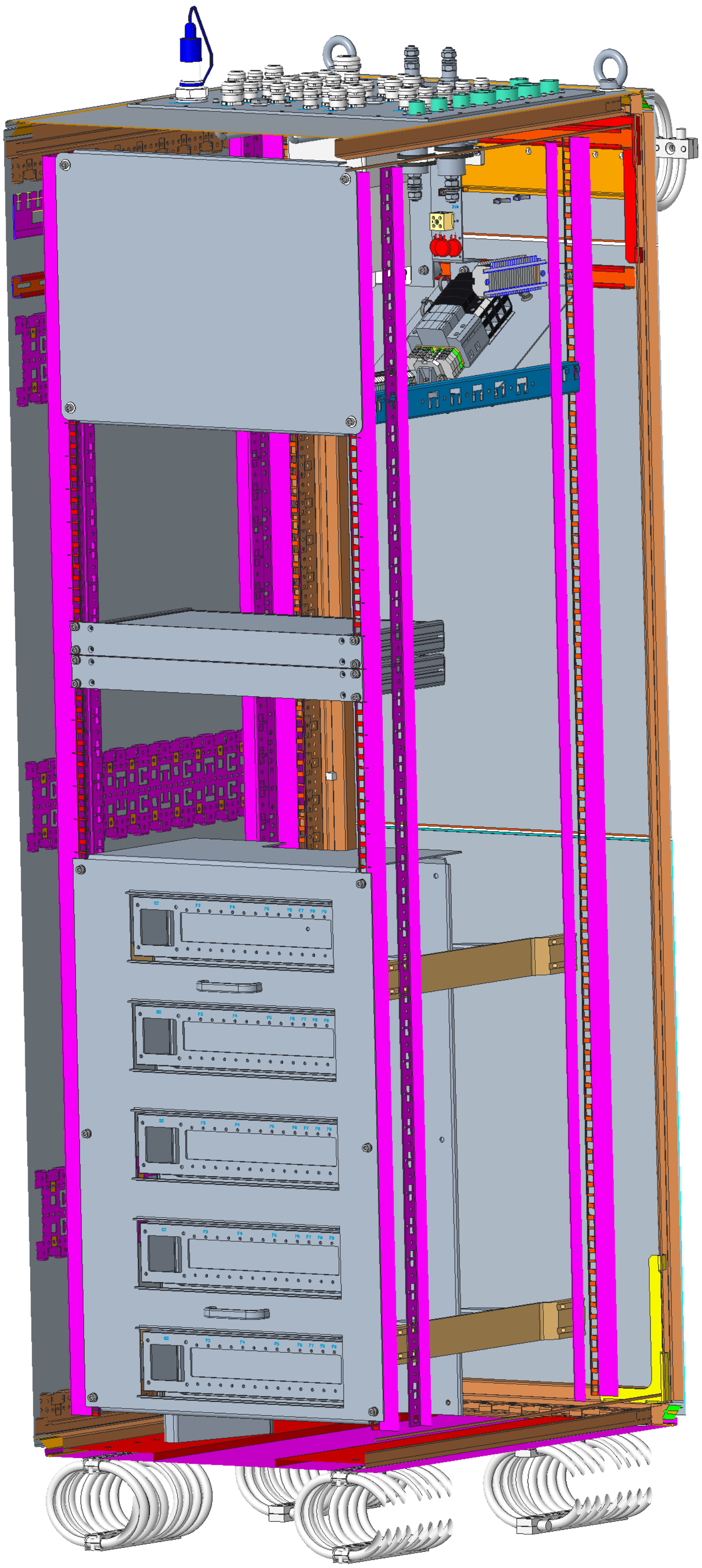

**Figure 9.3:** The final *Bravo* concept with front and side sections removed.

The units within the PDS are one in-house developed unit and stackable COTS PDUs. The COTS PDUs carry the simpler power distribution. The number of COTS PDUs to include depends on each customer's requirements. As discussed in Section 6.3.4, deciding the exact COTS PDU to implement could not be decided in this thesis, but will have to be decided by the Quality and Purchasing departments at Saab. However, to show how the COTS PDUs would be implemented, two 1U 19-inch metal cases were imported into the model to resemble the COTS PDUs. The market's offerings could be larger, but as can be seen in Figure 9.3, the chassis allows for both larger and more units. The fuses of the COTS units should be placed at the front for easy access, and cable bushings should go at the back.

The in-house developed unit is placed at the bottom of the PDS, where it rests on the floor of the chassis and is fixed by beams and fixtures on the sides of the rack, see Figures 9.4 and 9.5. The unit is covered by a metal housing that protects the user from involuntarily interfering with the components and cables. The metal housing is fastened in the rack of the chassis. To remove it, one loosens the screws and lifts it off by gripping its handles. At the top of the housing, there is a cable hole where cables travel from the unit to the rest of the PDSs' units or up to the contact plate.

The structure of the unit is in general made up of two layers that divides the components and fuses by separate metal plates, see Figure 9.6. The front plate is where the fuses and switches are mounted, and the back plate is where the components are placed. Between the two layers there is a distancing fixture that enables the front layer to open like a door. The front layer is fixed into its locked position by two fixtures placed on the side beams of the rack. The two fixtures are loosened when the front layer needs to be opened. At the back of the front layer, there is room for additional components. Cabling between components within the unit to the fuses and switches on the front layer run along the unit's left side, where the door is hinged. The cables can then easily follow the movement of the front layer when opened.

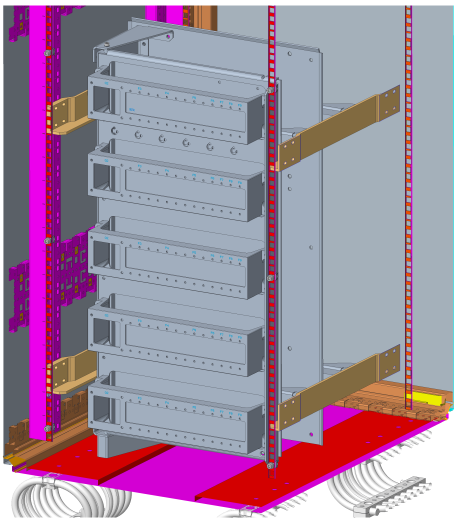

**Figure 9.4:** *Bravo's* unit without the metal housing viewed from the front.

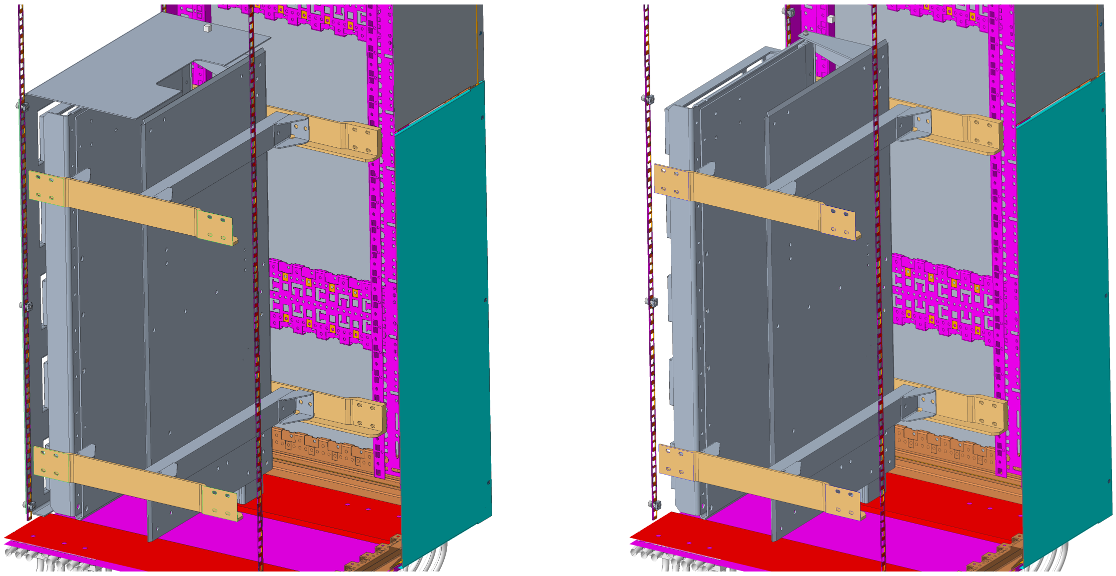

**Figure 9.5:** *Bravo's* unit with (a) and without (b) the metal housing viewed from the back.

As previously discussed in Section 7.1.2, the limitation was made to exclude electrical components from the concept. However, a recommendation is to define a base requirement that comprises all of the requirements that are the same for all projects. The base requirements would enable standardization of parts, which would save development and production costs. For every new project, the development would then be focused on the project's unique requirements.

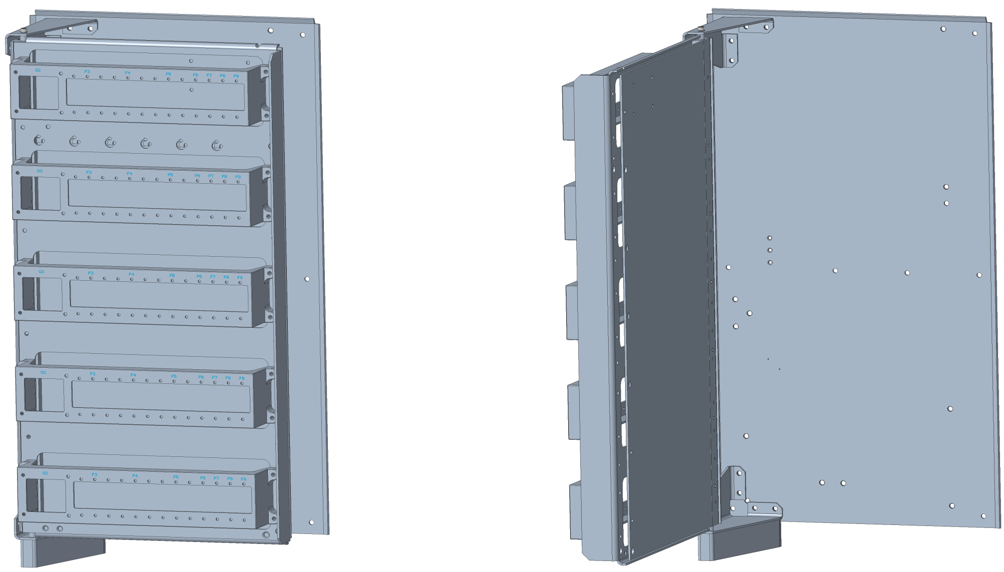

**Figure 9.6:** *Bravo's* unit with the front layer closed (a) and opened (b).

The *Bravo* concept of the next-generation sea-based PDS was developed on a system level to keep a holistic perspective of the product. It was designed to better fit Saab's low production volume where every project has unique customer requirements. The unit was designed with fewer and larger components, if compared to the Modular PDS. There was no need to divide the functions into individual units, but *Bravo* rather focuses on separating the base and custom requirements. The structure of the unit also enables an easy access of the fuses for the user, and of the components during service and production. The combination of COTS PDUs and one large in-house developed unit combines the best of both modularity and integration. The COTS PDUs saves Saab development costs by increasing flexibility through modularization. The integrated unit enables Saab to carry the more complex functions that requires in-house development.

# 10

# Recommendations

The following chapter contains the aggregated learnings collected from Saab employees during the thesis work at Saab. The recommendations apply to both the re-design of the PDS, as well as Saab's processes and the organization at large.

## 10.1 Product Recommendations

This section includes recommendations both specific for the PDS and more generally related to Saab's development projects where there have been found room for improvements. It regards general aspects of transparency, both regarding costs and regarding projects. It also includes recommendations on individual components and that Saab should define a base-requirement for the functions within the PDS.

### 10.1.1 Increase Transparency

In a company developing military-use products, confidentiality is natural. There are, however, some areas within Saab which could benefit from increased transparency, namely: costs of their products and how decisions affect the costs, and transparency on upcoming projects.

In the *Economic Analysis*, presented in Section 2.3, the Integrated and the Modular PDSs' product structures were compared to their respective production structure, which included the production costs. The production structure is the same as in Saab's PLM-system, IFS (EQT, 2014), which is used by all Saab personnel. Problems occurred when the production structure, only sometimes, did not match the product structure of how the components were actually assembled. Expensive parts could, thereby, be included in levels of the production costs where they did not belong. This caused problems when trying to connect costs related to physical components and, in extension, the larger sub-systems. A recommendation for Saab is hence to improve these structures in IFS to ease cost comparisons in future improvement work.

According to several managers, the design engineers do not focus on costs during the development work but rather focus on delivering a functioning product at the set deadline. Although, not all engineers have cost insights either. If the engineers were encouraged to take more cost responsibility, perhaps it could trigger innovation and lowering the overall costs. A better structured PLM system, with increased cost transparency, could increase engineers' feeling of responsibility for the costs. It also becomes a management issue to encourage such a change with the employees.

During the interviews, see Chapter 3, and further discussions held with the design engineers throughout the thesis work, it became evident that development costs could be minimized if they were notified of the requirements of both ongoing and upcoming projects. The development work of the design engineers is financed by the project that they are currently working on, which is strictly budgeted by the project's project manager. In general, the project managers are restricted regarding development work that is not directly connected to the project's delivery. The design engineers stated that by being notified of upcoming projects, they could design products to fit several projects. Even though each project has unique requirements, the design can be adjusted so that less alterations have to be made in following project, which in total would save development and production costs. However, the projects at Saab are long, few, and confidential which means that there might be issues in defining product requirements of the upcoming projects early.

### 10.1.2 Replacing and Removing Components

In Section 7.1, the transformer was previously debated. In both the Integrated and the Modular PDS there is a large transformer that converts the 400 VAC to 200 VAC, see the *Function Analysis* in Section 2.2. The transformer weighs about 20 kg and resulted in the PDSs' having to be reinforced with extra beams and fixtures to carry the heavy weight. The design engineers explained that the 200 V current only provides power to a special fan placed inside of the radar. If the fan was to be exchanged to one that requires 400 or 440 VAC, or 28 VDC, the transformer could be removed. By replacing the fan and removing the transformer, the PDS would require less mechanical reinforcement and would save space within the PDS. However, a new fan would have to be validated for the radar to ensure fulfilling the requirements, which is costly. Although, when choosing between validating a new fan, which is a one time cost, or keeping the transformer for every produced PDS, the recommended option is the latter in a long term perspective. The Design Engineers are aware of the challenges connected with the transformer and their ambition is to bring the issue further to management level, so that the transformer can be removed. The recommendation is for Saab to create an errand to replace the fan and remove the transformer.

On a more general note, Saab should aim at decreasing their amount of individual components in their products, and that those used should be standard components, if possible. During Chapter 8 *Verify Production Concept*, while trying to identify individual components costs, it was found that some non-standard mechanical parts were oddly expensive. When assessing the PDU of the Integrated PDS, there were many different sizes of screws and washers used when they could have been a standard size. As Saab's production volume is generally low, their custom parts carry a lot of costs. Saab would benefit from assessing their products and try to keep a higher degree of commonality, even across their departments, if possible. *Bravo's* COTS units are basic PDUs which could be analyzed on a larger perspective to also fit Saab's ground-based products. Their naval and ground-based products' requirements differ some, but if the PDUs would comply with the strictest requirements, this should be a possibility. Stricter requirements might, however, increase the risk that the purchasing price becomes too high to motivate such an investment. Regarding Saab's air-born products, the weight and size requirements might be too strict, but could also be assessed if it is a possibility.

### 10.1.3 Defining a Base Requirement

As previously discussed in Section 7.1, Saab's radar systems are unique and highly technological, and buying a radar system is a large investment for Saab's customers. That is why Saab develop their systems to fit every customer's specific requirements. It is therefore challenging and expensive for Saab to create a product architecture to adapt to every customer, while having a low production volume. During the thesis work, the question has been asked to many of Saab's personnel if they could define a maximum capacity limit for the PDS, so that it could be designed thereafter. It turned out to be the million dollar question. Several attempts were made but without any success. The maximum capacity need is in a sense undefinable, because whatever the customers want, Saab will try their best to provide. Therefore, our recommendation to Saab is to instead define a base-requirement that comprises all of the requirements that are the same for all projects.

The base-requirements would enable standardization of parts and processes, which would save development and production costs. For every new project, the development work would only be focused on the unique requirements and how they are connected to the base-offering. This is first and foremost an electrical engineering issue and could probably fit as a thesis project to develop e.g. a base-product, modular PDU to go with the *Bravo* design.

## 10.2 Organizational Recommendations

This section includes recommendations based on the learnings from the thesis regarding organizational aspects. It includes both how Saab should assess what decisions they make in their projects to benefit them in a long-term perspective. It also includes a reflection on how their resource allocation between the project and line organization seems misaligned, or how this balance is not communicated as well as it could be.

### 10.2.1 Long-Term Investments

As previously mentioned in this chapter, development work at Saab is financed by the project. It is an efficient way for Saab to ensure that each project sticks to their budget and deliver what is promised. Be that as it may, it leaves little room for innovation in larger development work of their products for long-term profit. During this thesis' many interviews and meetings, the general idea seems to be that project-related development is driven by short-term perspective decision-making to stick to the budget in terms of both time and money. The reason is understandable, but long-term investments such as, e.g. researching COTS PDU alternatives, could benefit several departments and their respective projects. In the long run it could benefit Saab's technological advancements, lowering their overall project costs and in that way develop and produce superior products to their customers. Such investments, especially in the case of COTS PDUs, could become a platform for all applications' different products: naval, land, and air-born. Related to this, the different departments at Saab could benefit from increased knowledge-sharing across departments. Through mentor meetings with personnel with varying experience within the same area, Saab employees do share their learnings on some product development. Yet, it still seems like the engineers have to re-invent the wheel in every new project. Practicing knowledge-sharing across departments could decrease development cost and time, and increase product coherence.

### 10.2.2 Project vs. Line Organization

Even though Saab is mainly a project organization, they also have a line organization aimed at executing larger development projects. The general idea, however, is that some departments manages this balance better than others.

Project managers presume that line managers should supply the resources for larger development efforts, while the line managers presume that project managers should budget the necessary development for their project-related needs. Both sides' arguments are fair and understandable, but for the sake of the organization at large, they could benefit from a re-establishment of expectations and responsibilities. If this balance would become more stable, perhaps it would be easier for Saab to invest in the long-term decisions in projects as discussed in the previous section.

### 10.2.3 End-user Communication

The last recommendation regards how Saab could increase product insight by getting first-hand information from the users on how the products are perceived, e.g. regarding areas covered in the Performance Parameters, see Chapter 3. What the many meetings during the thesis portrayed is that system designers and managers are the main contact with customers. The customers are not the users of the products, and hence the information on the user needs is at least third-hand information for the design engineers developing the products. If there would be a way for the design engineers and the users to communicate, the user satisfaction and product innovation could increase. Naturally, this is a question of both confidentiality and development resources, and perhaps does not have to be assessed in each new project. However, a continuous dialogue with the end-user could increase Saab's product's quality and customer satisfaction.

# 11

# Discussion

The final chapter of this thesis concludes some points of discussion regarding both the results and the process which took us there. It includes justifications for some choices made, criticism on specific aspects, along with some limitations and areas for improvement. This chapter also includes a discussion on ethical implications when developing products for military use. Lastly, a discussion about the sustainability aspects regarding product development to this project in particular.

## 11.1 Reflections of the Results

The *Bravo* concept is a system-level concept, taking many different stakeholders' considerations into account. The PDS is a very complex system within power and electronics, which are neither of our areas of expertise. In a sense, this made it easier for us to ignore components and details, and instead focus on general functions, mechanical design solutions, and product architecture. This was a large scope, which we were aware of at the start of the thesis. The aim was to successively narrow the scope, as we would learn more about the product, it's applications and limitations. We did, however, not manage to find a good way to limit the scope as the functions within the system are coupled and complex. This is why the *Bravo* concept has a low level of detail. We have instead delivered a well-motivated, mechanical design concept on a system level. More detail could have been included if the time would have allowed it, such as investigating specific components that influence the design. Such components could be the choice of switches and fuses, to go with cable bushings or contacts, or whether or not circuit boards are a mature enough technology. What technology and which physical components to use were largely discussed topics during the thesis, even though they were excluded from the thesis due to the limitations. Saab's engineers hold greater knowledge than us in these areas and would make better decisions in a fraction of the time it would take for us, which makes the limitation feel valid even in retrospect.

The *Bravo* concept has a 19-inch standard design, using the very same outer chassis as the Modular PDS and mostly the same design of the Integrated PDS's PDU. This unit is large enough to hold all the components included in the PSI of the Integrated PDS and has room for capacity expansion if required. This high level of re-use might make it seem like there is a low level of innovation, but we want to highlight the effort we put into finding other possible chassis and unit designs. As we motivated in the report several times, the main focus of the thesis was to focus on lowering costs, where validation holds a large part, although being a one-time-cost. The engineers at Saab have made valid design choices in their previous designs, even though costs might not have been their main focus, an issue discussed in the *Recommendations* in Chapter 10. The *Bravo* concept hence combines their clever solutions into a cost-effective, producible design fit for Saab's customers' specific requirements.

## 11.2 Reflections on the Process

The thesis followed most of the steps and recommendations of Ulrich and Eppinger (2012), which was a good way to stay on track and moving forward systematically. It did cause some application misalignment and had to be adjusted to fit the thesis. In retrospect, it might have been more efficient to only be influenced by it, instead of trying to fit the project to it the best we could. Their process did, however, act as good support for motivating the different choices of going about the process.

We started with setting off several weeks to simply understand the system, and how the functions were connected to components and parts. Our two supervisors, one mechanical engineer and one electrical engineer, were of great support when dealing with this. If the thesis were to have included an electrical engineering student, we believe that the start-up phase would have been much more efficient and perhaps the result could have included a higher level of detail. With that said, it has been very valuable for us to gain insight into how we as soon-to-be mechanical design engineers can work with products which main function is within power and electronics. A recommendation for Chalmers University of Technology is hence to include more electrical engineering basics into the Mechanical Engineering program.

Regarding the PDS's complexity, we were very dependent on Saab employees knowledge-sharing on their long experience of, mainly, the product, but also the organization. Hence, a large part of the process involved meeting and interviewing various actors for their valuable input on their own perception of the product. This was very time-consuming. What we want to highlight in this context is that Saab seems to have a great policy regarding helping colleagues when needed. We rarely had any set-backs when requesting a meeting or an interview with engineers as well as managers. Regardless of their position, anyone seemed eager to help and we are very grateful for that. It did however slow the process down many times as important decisions had to be postponed due to meetings being re-scheduled or sometimes canceled.

While on the topic of interviews, we have stated several times that Saab's customers have high demands on customization. It would have been preferable to interview some customers to get first-hand information on their perception of the system and how they use it. We do understand the confidentiality reasons to why this was not possible and are pleased that we could get second-hand information from the Service

Lead instead. When speculating on which components, such as fuses and switches, would be best suited for *Bravo*, the discussions mainly regarded guessing what the users actually wanted in both day-to-day and in crisis situations. Thereby, this aspect was a large part of the decision to exclude components from the concept.

As the thesis was carried out during the spring of 2020, it cannot go unsaid that the Covid-19 pandemic ravaged during this time and affected everyone, including our thesis work. We both got sick during a two week period and had no ability to work from home as this was in the middle of the thesis' process. As Saab's projects were not affected by the pandemic, as many other industries were, we were able to work at Saab's offices for the time remaining. For this we are very grateful as it would have been much more difficult to get on while based from home, as we were dependent on Saab's employees.

Two versions of the report was delivered, as the thesis includes some degree of confidentiality. One for Chalmers University of Technology which allows for publication, where costs and product numbers was censured, and one for Saab, where these numbers are required. As this was known stepping in to the project, the Saab report will include the same material as the censured report but with visual numbers, as it would serve the same value. For this reason, along with development projects nature of seemingly always running over the time budget, we had budgeted a good amount of time to write on the report during the last few weeks of the thesis. As the process was sometimes held up due to scheduling reasons, as discussed, we did most of the writing alongside the development. This allowed for thorough analysis, well-motivated conclusions and time for reflection.

## 11.3 Ethical Aspects

The ethical aspects of this thesis are very dynamic. As stated in the *Introduction* in Chapter 1, Saab provides solutions, services, and products from military defense to civil security to the global market of governments, authorities, and corporations. This can be argued ethically both positively and negatively, depending on one's individual perception of the cause. Saab's vision is that it is a human right to feel safe, and that they provide products which enables that. One could argue the opposite, that the products instead enable conflict. The thesis was carried out at Saab Surveillance, which develop and produce security and safety solutions for surveillance, decision support, threat detection, location, and protection. Their product portfolio includes ground-based, airborne and naval radars, combat systems, electronic warfare and C4I solutions. The PDS covered in this thesis is a naval radar PDS, which itself i not an offense product, which from an individual standing point feels morally better, even though one is aware of that the product could be used to aid offensive actions.

Nye (2006) writes philosophically about the impact technology has had on our lives for better and for worse. He discusses the increased risks of increasing technology use, particularly in warfare applications. After many historical notes, he gathered statements that can be summed up into: if an enemy nation knows that a country has a high capacity for defense, they will not attack. He then opposes with the following statement: "*The atomic bombs dropped on Japan did not discredit weapons of mass destruction but stimulated their production.*" (Nye, 2006, pp. 175). However, surveillance products can and should not be compared to nuclear weapons, but it does relate to the moral of developing military application products.

## 11.4 Sustainability Aspects

The three pillars of sustainability are: environmental, social and economic. Most of the social implications were discussed in the previous section on *Ethical Aspects*. Regarding both economic and environmental sustainability, the nature of the thesis project favored both. Even though new product development is resource demanding, the thesis was focused on lowering both costs and the number of adjustments to the design per project in a long-term perspective. The new design *Bravo* re-uses a lot of parts from the Integrated and Modular PDS, and has a strong modular connection, allowing savings in both development hours and production costs. Additionally, *Bravo* has a reduced number of parts compared to the Modular PDS, which decreases the amount of material and thereby also the weight of the PDS. It saves in material utilization and makes handling during production and service more manageable, which can contribute to less usage of lifting machinery and fuel consumption during transportation.

As for the realization of *Bravo*, Saab should consider their sourcing decisions as a simple way to minimize negative environmental impact. This could be fulfilled by using materials of lower negative impact during the entire product life cycle, or analyzing the logistics to minimize the impact from transportation. Through sourcing, Saab could also take social sustainability responsibility, e.g. by using suppliers with fair wages, no child labor, secure working environments, etc. After consulting several employees at Saab's Purchasing Department, it was clear that they do a thorough assessment of their potential suppliers and this should hence not be an issue.

As was discussed in the *Recommendations* of Chapter 10, the engineers developing Saab's products could decrease environmental impact and better their circular economy by increasing cost transparency, and thereby their responsibility over projects' costs. Applying platform thinking and working with modules where it is possible could decrease negative impacts of new product development, creating variants of the same PDS rather than re-inventing the wheel in every project. It should not go unnoticed that while the COTS units in *Bravo* decrease development costs and hours, and customization per project, it simultaneously increases material utilization. The idea is that working with variants and modular COTS units should in a long-term perspective require less resources overall.

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# Appendices

# A

# Interview Results

The interview results are presented as follows: System Design, Design Engineers, Service Lead, Customer and End-User and Industrial Engineers.

## System Design

Two people were interviewed with input from a system perspective. They both had management positions and were responsible for the development of the Modular PDSs. One interviewee was a System Lead, whom are responsible for the delivery of the radar system for each project. At the time of the design transition, he was the Technical Product Lead (SD1), i.e. a technical advisor regarding the products in each project. They make sure that the delivered products are on the right track regarding technical development and handles product specifications. The other interviewee was a Manager of System Design Airborne Engineering, and was at the time of the design transition Manager of Subsystem Design Mechanics (SD2).

#### The reason for changing the design

When asked about the design transfer from an integrated to a modular structure, there was prior to the first interview with SD1 no documentation on the matter. It then became clear that the underlying reason for a design change at the time was due to an increased need of capacity for that particular project. This brought that the then current design of the Integrated PDS could not fit the additional components, and hence a new design had to be made. These reasonings were also underlined by SD2, who also added that there was a wish to transition towards standardization of Saab products.

A team of Project Managers, experienced Design Engineers, System Leads, etc., then held a meeting on how to handle and design for the exceeded requirements of the PDS. They proposed three alternatives: to expand the current integrated design to fit the new components, to simply double the Integrated PDS's PDU, or to produce a new, modular, 19-inch design. The alternatives were evaluated on four elements: development cost, production cost, risks and what benefits each could bring about.

### Choosing the 19-inch chassis

According to SD1, the choice to go with the 19-inch chassis solution was based on that the production cost was estimated to be lower, even though development cost ought to be higher, than the other new product developments (NPDs) alternatives. The 19-inch solution was already applied in another technical area of the same project and that team responsible was sought to put on the re-design project. The production cost was estimated much lower than the two other alternatives due to the use of consumer off-the-shelf (COTS) products. SD2 explained how they [managers] tried to move away from the idea that Saab's products were so unique that they were not possible to standardize. The idea was to use COTS as much as possible, where applicable, as those type of products were not within Saab's core anyways. SD2 added that the customers of the project also had to be satisfied with the new product design, as they had expectations on what should be delivered. The 19-inch chassis solution was assumed best suited for this. SD1 continued that the risks related to the new, Modular PDS were lowest and regarded regular risks of NPD and those related to the technological advancement that required the design change. SD1 also explained that it was believed that the weight would become greater than that of the Integrated PDS, but not by much.

The benefits to enjoy from the Modular PDS were assumed to be a clean verification of specifications, according to both SD1 and SD2. SD1 explained that verification activities are not assumed value adding, but rather a necessary evil, and hence are not generally prioritized. The result is that when modifying a product, one builds up a 'debt' as only the modifications are verified, and not the entire product. The Integrated design's verifications were themselves not as up to par as they could be, as there were not enough resources. Going with the modular design was, therefore, also a way of increasing technological advancement and leaving the Integrated PDS behind. Lastly, it was assumed that the 19-inch chassis would be the most cost-effective alternative for a base-product such as the PDS as the modularity would allow for easy serviceability, highlighted by both SD1 and SD2. SD2 addressed the possibility of modularizing depending on the customers need for capacity.

### Realization of the Modular PDS

First off, the team that was supposed to be brought over to the development of the new PDS were not available resources and so knowledge transfer was much more difficult, SD1 sated. Furthermore, he continued, the development and production costs were a lot higher due to the required alterations to the COTS products, to comply with military requirements. SD1 agreed, stating that issues with cabling between units being the main cost driver. Weight and volume were also much greater than estimated, according to SD1.

### Additional reflections

SD1 stated that even though the new design was not without issues, the two other alternatives have not been explored and hence it is unknown if this was not the best solution after all. He continued saying that there is little risk of future customers requesting the same increased need of capacity, as for the project leading up to the Modular PDS. There has not been such a request since, but if such an order would be placed again, SD1's recommendation was still to go with a 19-inch chassis. The same goes for SD2 who believes that a scalable, modular units would be cheaper in both development and production costs. He was however aware of modularity being difficult as, even though the parts are not COTS, each project is still unique to each project and that military requirements are usually not fulfilled by COTS parts.

It was no surprise to SD1 that the integration, i.e. the chassis and mechanical parts, were the main cost-drivers of the PDSs. Electronics is always purchased from suppliers, he said, but to produce power systems is not for a standardized market. The military environmental requirements are not cheap to verify and to buy COTS is not possible without adjustments. There are two ways of going about the sourcing, both SD1 and SD2 stated: Purchasing COTS goods and adjust them to fit the requirements, or to develop in-house and produce it in-house or outsource. SD1 explained that to outsource completely is costly as suppliers have their own profit margins, and the activity itself is not risk-free. Risks relate to loss of control and late occurring costs in the production timeline. It is commonly cheaper if one could source from international suppliers, but this complicates communication. Some customers are also not comfortable with sourcing of materials in their systems originating from certain countries. To produce in-house in highly resource-demanding and heavy on development costs. However, when weighing the two options and asked about what they would prefer, both SDU1 and SDU2 answered that they prefer COTS over in-house production, despite the many challenges. The System designers have a holistic perspective of the products, systems, and have close contact with other senior management. Together are they striving for implementing more COTS parts into Saab's systems, so to decrease complexity and increase standardization. They want to move away from the perception that all of Saab's products are specific and complex, even though that often is the case.

## Design Engineers

Three design engineers were interviewed to cover the information from their perspective. The design engineers at Saab receive product specifications of what is to be delivered for a project. They then carry out the design and documentation of the products of the project to enable production. The first interviewee was a mechanical engineer (DE1), who helped develop the mechanical design of the Modular PDSs. Has also worked with the Integrated PDS to a great extent. The second interviewee was an electrical engineer (DE2), a "kraftkonstruktör". He had worked with both but mainly the Integrated PDS. The third interviewee was also an electrical engineer (DE3), "kraftkonstruktör", who had the sole responsibility of designing the Modular PDS. Due to limited resources and time, DE3 also helped in designing the mechanical aspects of the Modular PDS.

#### Benefits and Drawbacks of the Modular PDS

When asked about the benefits of the Modular PDS, DE1 said, and DE3 agrees, that the modular set shortens the development work, as you do not have to re-invent the wheel each time. The documentation is already done and e.g. only holes for the back plate [for cabling outlets] has to be added. Another benefit is that it enables concurrent engineering, but highlighted that it is not necessarily cheaper to let each engineer work on one 19-inch box - it is just as expensive to have one engineer work on each one after another. Additionally, a benefit of not only the Modular PDS, but the modular set of the 19-inch standard, is that it is used in more of Saabs products. When the systems are delivered to the customer, who has more than one of Saabs products, DE3 thinks it gives a professional and cohesive impression.

Although, when asked about the drawbacks of the Modular PDS, DE1 explained that the biggest delimiting factor with the modular set-up has to do with the 19-inch chassis units. The rack has to be a lot higher than the units stacked upon each other, as each require added stiffeners and fasteners due to the weight of each unit when they reach three to four U [height unit]. DE2 agreed by saying that the 19-inch, modular set is much more complex to design, produce, and is a lot larger in volume. DE1 thinks that each box is very cramped and the cabling outlets do not always fit. DE2 concurred about the extensive system cabling, that it is hard to fit into the cramped chassis, and added that it is expensive regarding materials and production hours. Hence, the space in the rack is not optimized as the units cannot carry that much weight.

DE2 explained that the 19-inch units are not made to carry heavy equipment and hence require a lot of re-work. DE1 elaborated by saying that the current design's 19-inch chassis rest and is upheld only by screws on the front plate - no rails or anything. This is why additional mechanical parts needs to be added. The cabling between the boxes is also extensive, they all pointed out. All in- and outlets of the PDS are placed at the top of the rack. DE3 explained that he designed the placement of the 19-inch chassis to be close to the top, so that the cables could be as short as possible to avoid loss of voltage. However, this meant that the heavy units, e.g. PDU2 [which contains the heavy TRAF], were placed in the middle of the rack, and therefore needed extra support to ensue a durable structure. Space was left at the bottom of the rack to allow future additions to the PDS, continued DE3, but there is no indication for now that it would be needed. DE3's statements therefore explains why the 19-inch chassis are placed in the middle of the rack, instead of being supported by the rack's bottom plate.

Talking about modularity, DE2 believed that there is a different meaning to the word 'modular' depending on what aspect it regards. The 19-inch solution requires modifications to each unit as each project has different requirements, hence they are not modular more than that the units have a standardized height and fits into a standardized rack. He reckoned that the future will still include 19-inch units, as it is a validated construction and is used broadly within Saab's product portfolio. DE3 believes that the modularity of the 19-inch chassis is something that is mainly for the benefit of the Design Engineers, to save in development hours and in the long run production hours, as long as the variation between the projects only differ in a few variants.

### Benefits and Drawbacks of the Integrated PDS

When asked about the Integrated PDS, DE2 expressed that the integrated design is an old solution and this particular one had been applied in projects a few times. Production hours are a lot fewer because of the system cabling required between the units. It is also a lot more spacious than the modular set-up, which allows for easy modifications, in relation to the modular where the space is much more cramped. DE1 felt that the structure of the Integrated PDS is less complex to develop and work with. However, DE1 said that an issue with the integrated design was that the circuit boards [SOL and MFG] were hard to reach from the front. He believed that the Integrated PDS has a lot of room for further development and adjustments to the base product.

DE1 explained that there is almost no cabling between the two internal chassis, as in the Modular PDS, but rather between components within the PDU and PSI with some few cabling externally drawn between the chassis. The PDU and PSI have their respective electrical environmental zone. The PSI is an add-on to the old system when it only consisted of a PDU. He argued that there is no reason why the two chassis can not be combined into one single unit. DE3 and DE2 both agreed that all electronics can be integrated, but as long as there are some form of mechanical partition, or that the cabling for each voltage are sub-organized [to avoid mixing them together]. Likewise, you do not want high frequent transmitters close to the power distribution, as they can disturb each other.

### Challenges

DE1 said, and DE3 agreed, that the customer requirements regard functions, and not design solutions. The engineers have freedom in designing the solutions, but not in function. The most limiting requirements regard the military requirements for temperatures, electrical environment, withstanding mines, etc. Using contacts or cable bushings does not matter for the customer, thus the contacts are never, or rarely, disconnected during the product lifetime. DE2 explained that the product specifications they receive are from the project management, whom in turn has retrieved them from the customer. He went on to say that some specifications are common ones that regards military requirements, which are not up for discussion. However other requirements usually regards functions which they can design however they want. If customers have expressed explicit demands on features, they try to accommodate them but if it is not possible, Saab can always re-negotiate. Regarding restrictions on volume, the naval applications are much more forgiving than ground-based applications as the PDS is placed in a large machine room under deck, said DE2 and DE3. A standard measurement is 800x800x195 cm, but one does not have to follow it. DE1 believes that it is thought of like a recommendation and a guideline.

Saab has started launching systems with circuit boards, which according to DE2 will be the future of these systems. To move over to this type of solution, DE3 said, it would have to be funded by the department, and not by the project [that they are currently developing, which is the common source of development resources]. DE2 lifted the possibilities of newer alternatives, and has influenced more people to gain an interest. A large cost contributor is cabling that could be minimized through using a more digitized solution.

Generally, production are included for support and feedback early on in the processes, said DE2, as they hold a lot of know-how on how much space is required for cables, how long it will take, etc. However, when development of a new product is done, it is sent for production without complete documentation as the designers wants it to be a trial-and-error type of process. Some things are impossible to know without trying it out, explained DE2, and it is too expensive to make prototypes. Hence, several weeks go into meetings of testing and revising the design. When designing the Modular PDS, DE3, would have needed to make a prototype. Although, due to lack of resources and time, the design had to be altered as they went along in the production. As there were so many adjustments to the design, DE3 ended up being the only person who knew what was going on.

When designing for these complex and unique project designs, DE2 believes that it is important to gain insight into future projects. If he would know early on what would be the next upcoming project, he would have the possibility to design a solution that could also be used for the next project. Although, due to the long time-span between the projects such information is hard, if not impossible, to receive in time. This is a setback in Saab's current structure. Knowledge sharing among designers happens through both relaxed and more official manors, through peer reviews, mentor-ships among junior designers and inspections.

## Service Lead

The interviewed Service Lead was the only one with extensive experience of both the Integrated and the Modular PDS. As there was only one interviewee of this position, the following statements are all his. The role of Service Lead is to receive the finished PDS, start it up and run it together with the other systems of the radar for the first time to eliminate issues. They also check that the SOL starts the different functions with the correct sequence, checks if the voltages are correct and then runs the system for a longer period of time to ensure its durability before delivery. The Service Lead also supports the design engineers in their development work, mostly regarding hardware updates due to issues that comes up during their tests when handling the chassis and components. The Service Lead also meets with the customers to set the system up at the ship and performs the necessary tests to again check for durability.

When asked about the Modular PDS, he explained that he believes the main issue of the Modular PDS is the cabling, which is very expensive. Each cable requires a lot of manual work, and there are a lot of cabling required in the Modular PDS. A benefit of the modular set-up is that it is harder to make the mistake of connecting the wrong cable to the wrong component as they are separated into 19-inch boxes. Furthermore, he said that as the control interface is placed on the outer chassis, it makes it easier to work in 'packages' with one 19-inch box at a time. One can also break the power to individual units, e.g. have the 28 V running to provide power to the lights while working on one of the other boxes.

The Service Lead was then asked about the Integrated PDS and answered that it is easier to check if the cables are pulled to the correct outlets. Both due to that the AC and DC currents are divided into separate chassis in the Integrated PDS, and as all the components are exposed in the chassis it is easy to track each cable. However, he believes that it is harder to perform service in the Integrated PDS as there are more cables to pull, rather than working with said 'packages' in the Modular PDS.

The chassis of the Integrated PDS is a unique design. It was designed by Saab and produced by a supplier. The Service Lead explained that there have been some issues with previous chassis where the supplier did not receive correct or complete information, regarding e.g. which side to weld on the bottom plate. Problems with the supplier produced chassis could lead to the requirements not being fulfilled.

When asked about the PDS in general, the Service Lead states that he would prefer to have contacts instead of cable bushings everywhere . It would simplify his work when docking both the PDS and its units in och out. He also stated that a more spacious system is easier to work with, for him, and that volume is less of an issue for naval applications, if compared to the ground-based PDSs.

## Customer & End-User

Due to customer confidentiality, interviews with customers and users were not possible to perform. However, to gain the perspective of the customers, users and the setting where the PDS is used, the Service Lead was interviewed for this purpose. As stated previously, the Service Lead has experience of educating users about the radar system, having customer contact, and has visited the environment where the PDS is placed.

### User interaction with the PDS

When asked about Saab's involvement during the systems life-time, the Service Lead stated that service to customers is not always included. He explained that it depends on the contract, which in turn depends on economic aspects and how independent the customers want to be from external parties. However, few customers have the knowledge required to perform such service. Service that Saab offers can e.g. be refurbishments, where the customer sends back entire units for fixing. As most of the technology is customized, there will come a time where they have to update it with the use of Saab expertise. These are more long-term situations. On a shorter time-horizon, customers can receive education on what maintenance they can do themselves, during different intervals, which is required for a long product lifetime.

They can also receive some spare parts, such as filters, switches, fuses and circuit boards.

A common use situation is that customers use the outer interface of the PDS and turns a switch to 'remote' or 'off' mode. When they want to start the system, they choose 'remote', goes to a separate control room and starts the system from a PCP. The PCP can either be placed on the outside of the rack's chassis or be operated remotely. The control room can be a few minutes walk from the machine room [where the PDS is located] on the ship. When turned on, he states, he radar, and hence the PDS, commonly runs for a long time - perhaps a month at a time. Other use situations are e.g. in case of fire or other emergencies where they turn the system off. If a customer is not going to use the radar for a while, the system is turned off and the fuses are checked.

When asked about the users handling with the components of the PDS, the Service Lead explained that the only reason for users to enter behind the second security-plate of the Integrated PDS or open up the 19-inch units in the Modular PDS, is for service reasons, and that requires special education. Installation technicians know this work. They should preferably not ever do this. In some cases we have customer support teams on call during the first few months, or by e-mail when needed later. Customers usually ask for help with debugging, not rarely if there have been a lightning strike, which requires a change of the lightning protection.

**Customer feedback**

The challenge with naval applications is the requirement of long cables. Something that users have commented on is the Integrated PDSs outlets on the sides. There is usually little floor room in the machine rooms, and bending of cables to reach from the ceiling down to the outlets on the sidse requires a lot of room. The Modular PDSs gathered cabling at the top is hence a better solution, the Service Lead believes. The ships design engineers mainly care about having the correct weight distribution, but not so much about volume.

# Industrial Engineers

The Industrial Engineer interviewees were two people responsible for the production process. One of the interviewee was the main person responsible for the production of the Modular PDS and had worked closely with the Integrated PDS as well. The other had also worked closely with both PDSs. As there was only one joint interview, the answers were not explicitly one persons opinion or experience, but they rather filled in on each other's statements. They shared the same opinions so extensively that their answers were fully grouped together in this summary.

The role of an Industrial Engineer is to act as support to mechanical and electrical designers to aid the development work. They then keep the communication between production and design departments both early on in the development work, and during production, where they hold 'hardware reviews' where they give feedback on the design. Such feedback could include pointing out sharp edges and additional space required for cabling. They are responsible for the production process.

### Benefits and Drawbacks of the Modular PDS

The biggest differences between the two units, according to the Industrial Engineers is size, weight, cabling and space. The Modular unit is much larger in size and weight, requires more system cabling due to connecting the units and is perceived more cramped. The benefit of the modular set-up is that production personnel can work on the units concurrently, but then only one person can be responsible for integrating the entire PDS in the outer chassis [as there is where it is cramped]. They clarified that the COTS units and the rack are modified for customization by milling and surface treatment at Saab and then sent to storage for production to pick up.

If one has to perform service, each unit has to be fully removed from the chassis to reach the parts, the Industrial Engineers explained. They also made clear that an entire unit is never a spare part, but is rather small components such as a circuit boards, filters and cassettes, which according to some contracts has to be delivered and changed within a few hours. Mechanical parts are usually not spares, they added.

### Benefits and Drawbacks of the Integrated PDS

The Industrial Engineers explained that in the Integrated PDS, at least two people can work on it simultaneously, one on the PDU and one on the PSI. In production, one can reach inside the Integrated PDSs PDU and PSI respectively from all directions, as everything is assembled on a base plate, which in upright position becomes the back of the unit. As the Integrated PDS has been produced more times than the Modular PDS it has been a lot quicker to produce. There is also a lot more documentation that has been developed and improved over the years.

### Why the outcome cost differed so much from the estimated cost

The Industrial Engineers, along with the Design Engineers, are responsible for setting the estimated production hours. They estimate it using an average of previous assembly times, or look to products with similar mechanical and electrical designs as references. The Modular PDS took longer to produce as each unit was its own product and hence had to go through 'hardware reviews' and completion before integrating the entire PDS. Lastly, the Industrial Engineers discussed how for each NPD the meeting hours are many, and they are not always included in the estimated time plan. For NPDs the estimated production hours can easily be doubled. The products are so complex and require focus that people are cautious of doing it wrong.

In the case of the Modular PDS, production got little documentation as the idea was to produce it in a trial-and-error type of way, the Industrial Engineers explained. This was decided as it would probably not be produced several times. The 'hardware reviews' then took much longer than expected. The most time-consuming activity in production is, according to the Industrial Engineers, the cabling and hence is the most expensive. Each cable requires marking, twisting, separating if needed, pulling and fastening them up to the top where the outlets are. As the system cabling was so extensive in the Modular PDS, this is a probable cause for its high production cost.

Regarding the outcome hours of the Integrated PDS [being based on an average of the three produced in 2019], the Industrial Engineers explained that they are probably skewed because of the first project, where materials planning went wrong early and delayed the process. The other two projects were much more successful. In the Integrated PDS, the process was shorter and had fewer steps until completion. They stated that they always run the risk of not completing on time, which in turn shortens the verification times and end up most stressful for those performing system tests [i.e. Service Lead].

# B

# Concept Requirements Specification

**Table B.1:** Concept Requirements Specification.

| Concept Requirements Specification | | | | |
|---|---|---|---|---|
| **Category** | **Criteria** | **Target Value** | **Verification Method** | **N/R** |
| **From standards** | | | | |
| **1. Climatic** | | | | |
| | 1.1 Temperature operation, T | +35°C >T>+15°C | Expert assessment | R |
| | 1.2 Temperature storage, T | +40°C >T >-25°C | Expert assessment | R |
| | 1.3 Temperature change | See Notes | Expert assessment | R |
| | 1.4 Low air pressure | >87 kPa | Expert assessment | R |
| | 1.5 Low air pressure during transport | >15.4 kPa | Expert assessment | R |
| | 1.6 Humidity | Rh <70% @ 40°C | Expert assessment | R |
| | 1.7 Fungus | See Notes | Expert assessment | R |
| | 1.8 Protection by water ingression | See Notes | Expert assessment | R |
| **2. Mechanic** | | | | |
| | 2.1 Vibration, shipping and logistic transport, rail | See Table B.4 | Expert assessment | R |
| | 2.2 Vibration, shipping and logistic transport, jet aircraft | See Table B.5 | Expert assessment | R |
| | 2.3 Vibration, shipping and logistic transport, general transportation | See Table B.6 | Expert assessment | R |
| | 2.4 Shock, shipping and logistic transport | See Table B.7 | Expert assessment | R |
| | 2.5 Shock, transport during use | 100 m/s2 11 ms or 300 m/s2 6 ms. | Expert assessment | R |
| | 2.6 Ship motion | Roll: ±22.5°, period 7s Pitch: ±10°, period 5s | Expert assessment | R |

**Table B.1 continued from previous page**

| **Concept Requirements Specification** | | | | |
|---|---|---|---|---|
| **From Thesis** | | | | |
| **3. Cost** | | | | |
| | 3.1 Development Cost (DC), SEK | $\leq$ Modular PDS | Cost estimation | R |
| | 3.1.1 Flexibility (DC) | | | |
| | 3.1.2 Standardization (DC) | | | |
| | 3.2 Production Cost (PC), SEK | $\leq$ Modular PDS | Cost estimation | R |
| | 3.2.1 Cabling (PC) | | | |
| | 3.2.2 Materials (PC) | | | |
| **4. Usability** | | | | |
| | 4.1 Intuitiveness | $\geq$ Modular PDS | Subjective assessment | N |
| | 4.2 Reachability | $\geq$ Integrated PDS | Subjective assessment | N |
| | 4.3 Serviceability | $\geq$ Modular PDS | Subjective assessment | N |
| | 4.4 Spaciousness | $\geq$ Integrated PDS | Subjective assessment | N |
| | 4.5 Uniformity | $\geq$ Modular PDS | Subjective assessment | N |
| | 4.6 Visibility | $\geq$ Integrated PDS | Subjective assessment | N |
| **5. Design** | | | | |
| | 5.1 Dimensions | $\leq$ Modular PDS | Measure CAD-model | R |
| | 5.2 Weight, W | $\leq$ Modular PDS | Measure CAD-model | R |

**Table B.2:** Related notes and references to each criterion 'From standards', see Concept Requirements Specification in Table B.1.

| **Notes related to criteria from standards.** | | |
|---|---|---|
| **Criterion** | **Notes** | Reference |
| 1.1 | The equipment can be regarded as sheltered<br>i.e. will be protected from rain, water splash, snow, ice, sand and dust etc.<br>It is also assumed that sheltered equipment is subjected to active climate control<br>where temperature, humidity, sand and dust etc. may be controlled. | [1] |
| 1.2 | Naval, Below deck, air condition | [1], [5] |
| 1.3 | Temperature transients may appear in the various parts of the systems as a result of e.g.<br>a) Ambient temperature environment due to solar radiation<br>and temperature change in the diurnal cycle.<br>b) Induced environment around the object due self-heating<br>when powering up and down the equipment.<br>c) Induced environment around the object due temperature transients<br>of other heat sources in the vicinity of the equipment. | [1] |
| 1.4 | Minimum pressure at 0m level. | [1] |
| 1.5 | Corresponding to an altitude of 12000 m. | [1] |
| 1.6 | These environments represent extreme events obtained a few times during life time. | [1], [5] |
| 1.7 | The system shall not be susceptible to or be affected by<br>fungus growth i.e. no damage nor performance degradation. | [1] |
| 1.8 | Sheltered equipment shall be designed for IP-code 22,<br>Protected against dripping water. Sheltered equipment for compartments where<br>fire suppression systems with overhead sprinklers is installed<br>shall be designed for IP-code 23, Protected against pouring water. | [1], [2] |
| 2.1 | Acceleration spectral density (ASD) of a rail cargo transport.<br>Should be considered as real time ASD data. | [3] |
| 2.2 | Acceleration spectral density (ASD) of a jet cargo transport.<br>The levels cover most common military jet transports vibrations and represent<br>the envelope during the take off and worst case zone requirements.<br>The exposure duration shall be 1 minute per take-off and axis. | [3] |
| 2.3 | Acceleration spectral density (ASD) of a general public transport.<br>The levels apply to transportation by air, by road on all qualities of road surfaces,<br>by ship and by train. Accelerated test level and exposure duration is 30 minutes/axis.<br>The levels are less conservative compared to the previous description<br>of aircraft environments but does not apply to military jet transportations.<br>The requirement is applicable to logistic shipping of parts and accessories<br>e.g. spare part deliveries. The severity may be mitigated by packaging techniques. | [4] |
| 2.4 | Transportation to customer (transport A)<br>and destruction site (transport D). | [4] |
| 2.5 | Shock environment according to [6], Class 6M2.<br>Test according to [7]. | [4], [6], [7] |
| 2.6 | The equipment for naval system shall be designed<br>for full system performance during the following conditions. | [1] |

**Table B.3:** The standards used as base for the Concept Requirements Specification, see Tables B.1 and B.2.

| External Standards | | | |
|---|---|---|---|
| **Number** | **Standard Name** | **Includes** | **Citation** |
| [1] | STANAG 2895 | Extreme climatic conditions and derived conditions for use in defining design/test criteria for NATO forces materiel. | NATO (1990) |
| [2] | IEC 60529 | International Standard: Degrees of protection provided by enclosures (IPcode) | IEC (2001) |
| [3] | MIL-STD 810G w/ change 1 | Environmental Engineering Considerations and Laboratory Tests | DoD (2014) |
| [4] | ETSI EN 300 019-2-2 v2.1.2 | Specification of environmental tests-Transportation | ETSI (1999) |
| [5] | AECTP-230 (Edition 1) | Climatic conditions | NATO (2009) |
| [6] | IEC 60721-3-6 | Classification of groups of environmental parameters and their severities Section 6: Ship environment. | IEC (1987) |
| [7] | IEC 60721-4-6 | Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 - Ship environment. | IEC (2003) |

**Table B.4:** Target values related to criterion 2.1.

| **Target values related to criterion 2.1** | |
|---|---|
| **Frequency [Hz]** | **ASD [$g^2$/Hz]** |
| 1 | 0,00007 |
| 3 | 0,002 |
| 80 | 0,002 |
| 350 | 0,00003 |

**Table B.5:** Target values related to criterion 2.2.

| **Target values related to criterion 2.2.** | | |
|---|---|---|
| **Frequency [Hz]** | **ASD [$g^2$/Hz]** | **Slope [Db/octave]** |
| 15 | 0,01 | |
| 105,94 | 0,01 | |
| 105,94-150 | | 6 |
| 150 | 0,02 | |
| 500 | 0,02 | |
| 500-2000 | | -6 |
| 2000 | 0,0013 | |

**Table B.6:** Target values related to criterion 2.3.

| **Target values related to criterion 2.3.** | | |
|---|---|---|
| **Frequency [Hz]** | **ASD [$g^2$/Hz]** | **Slope [Db/octave]** |
| 5 | 0,01 | |
| 20 | 0,01 | |
| 20-200 | | -3 |

**Table B.7:** Target values related to criterion 2.4.

| **Target value related to criterion 2.4** | |
|---|---|
| **Mass, m** | **Requirement** |
| m >500 kg | No requirement |
| 500 kg >m >50 kg | Half sinus pulse amplitude 10g and duration 11ms, 100 bumps in 6 directions (3 orthogonal ± directions). |
| m <50 kg | Half sinus pulse amplitude 18g and duration 6ms, 100 bumps in 6 directions. |

# References

DoD (2014). *MIL-STD 810G w/ change 1:Department of Defense Test Method Standard - Environmental Engineering Considerations and Laboratory Tests*. USA.

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NATO (1990). *STANAG 2895: Extreme Climatic Conditions and Derived Conditions for Use in Defining Design/Test Criteria for NATO Forces Materiel*. Belgium.

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