Redesign of Gas Hydraulic Suspension for Product Service System

A Master Thesis Work at Strömsholmen AB

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Martin Ankarberg & Erik Jilnö
Abstract
In these times, when manufacturing firms wonder how to integrate products and services into innovative offerings, how should products be designed to be of most value? This study is the investigation of this question for the manufacturing firm Strömsholmen AB, which designs gas springs and hydraulic suspension. The research has led to interviews of personnel to identify challenges and a workshop to generate new service ideas. By analyzing a specific gas hydraulic suspension product, this study shows that designing for product service systems (PSS) with a life-cycle perspective specifically for manufacturing, assembly, delivery, use, maintenance and remanufacturing, can greatly reduce costs and open up for innovative PSS business models. Using Design for Assembly, Design for Disassembly, Design for Serviceability and Design for Remanufacturing shows how concrete improvements to a product can be made. Improvements that show the potential of a redesign for the gas hydraulic suspension. Integrating products and services and pursuing the ideas and methods of this thesis, will ultimately make Strömsholmen better prepared to differentiate, to stay competitive, to deepen customer relations and to gain greater profits long-term.

Keywords. Strömsholmen AB, Gas Hydraulic Suspension, Product Service System, PSS, Integrated Products and Services, life-cycle, DFA, DFS, DFD, DFRem.
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<th>Description</th>
</tr>
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<tbody>
<tr>
<td>DFA</td>
<td>Design for Assembly</td>
</tr>
<tr>
<td>DFD</td>
<td>Design for Disassembly</td>
</tr>
<tr>
<td>DFM</td>
<td>Design for Manufacturing</td>
</tr>
<tr>
<td>DFRem</td>
<td>Design for Remanufacturing</td>
</tr>
<tr>
<td>DFS</td>
<td>Design for Serviceability</td>
</tr>
<tr>
<td>DFX</td>
<td>Design for Excellence, the gathered abbreviation of DFA, DFM, DFS</td>
</tr>
<tr>
<td>H5</td>
<td>The term for the gas hydraulic suspension system with a maximum load capacity of 5 tonnes.</td>
</tr>
<tr>
<td>Hydrop</td>
<td>A term used by Strömsholmen for the products within hydropneumatic suspension systems — also known as gas hydraulic suspension systems for vehicles.</td>
</tr>
<tr>
<td>IPSO</td>
<td>Integrated Product Service Offering</td>
</tr>
<tr>
<td>Kaller</td>
<td>The brand name which Strömsholmens products go by</td>
</tr>
<tr>
<td>M&amp;V</td>
<td>Machines &amp; Vehicles, Product category at Strömsholmen</td>
</tr>
<tr>
<td>PSS</td>
<td>Product Service System</td>
</tr>
<tr>
<td>Tool &amp; Die</td>
<td>Class of products aimed at the manufacturing processes of other firms.</td>
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</table>
1 Introduction

Today, many firms set out to navigate the transition from a product-centric to a service-based business model. Away from providing a sole product offer to a more integrated product service offering (also known as IPSO). A change in view of what it means to provide goods. The shift in thinking results from a need to differentiate, to stay competitive, to deepen customer relations and to gain greater profits long-term (Kowalkowski & Kindström, 2012). Services of different types have become increasingly important for product firms (Cusumano, 2015) — Rolls Royce provides not only jet engines but a “power by the hour” concept, Scania has a mileage charge for their trucks and Volvo Cars offer private leasing of the XC40. Companies start to take responsibility for the whole life-cycle and — charge for the use of the product. Or as Peter F. Drucker (pioneer of modern management theory) formulates it — "No customer ever buys a product. He always buys what the product does for him" (Berger, 2015). The question is no longer whether companies sell products or services, but what services they provide when they take their products to the market (Kowalkowski & Ulaga, 2017). So how can companies become service-based when their historical roots are firmly grounded in product-centric logic? Should companies shed their historic product base and become service providers? Rather, the fundamental challenge for these firms is about service growth (see Figure 1) and finding smart ways to grow beyond the historic goods-centric core of these firms (Kowalkowski & Kindström, 2012). A domain that goes into hybrid offerings/solutions — products and services combined into innovative offerings (Shankar, et al., 2009, p. 95). The question then becomes — what unique opportunities exist that pure service players cannot access? What resources and capabilities can manufacturers leverage to build hybrid offerings (Ulaga & Reinartz, 2011)?

The effect of the service transitions across industries does not only affect customers and business models but puts pressure on the product development process of firms (Kowalkowski & Kindström, 2012). The incentive for planned obsolescence goes out the window and instead customers demand products that are sustainable and products that come without the risk of unpredictable repairs, which in turn they will pay for (Berger, 2015). To design durable products with a life-cycle perspective becomes therefore increasingly important (Sundin, et al., 2009). Namely, using different engineering methods and tools that would result in adaptation for manufacturing, delivery, usage, maintenance, disassembly, reassembly, testing, recycling and/or remanufacturing (Sundin, et al., 2009). The question that remains is if manufacturers can handle a service transition and at the same time design long-lasting products that are serviced in a cost-effective way? Addressing important phases in the life-cycle. The potential if successful could mean increased income, lowered costs and satisfied...
customers all at the same time. A company interested in looking deeper into this potential is the manufacturing firm Strömsholmen AB.

Strömsholmen have expressed an explicit need to look deeper into this potential for the gas hydraulic suspension systems they have developed. They want to know how they can be designed for manufacturing, assembly and especially disassemble and service? Since a demo dissembles was performed on the products, a realization occurred that ease of disassembly and service was overshadowed by the goal of providing the precise function to customers. The question going forward is, how can Strömsholmen progress in this matter? What product-usage data can provide insights into further developing the life-cycles of the gas hydraulic suspension system and how can they grow their service business?

1.1 Objective
The objective of this study is divided into two parts; one is to investigate how Strömsholmen can move towards more integrated product service offerings. The other part of the objective is how to actually design their products to be easily assembled/disassembled, serviced and long-lasting.

1.2 Strömsholmen AB
Strömsholmen AB develops, manufactures and sells gas springs for tool & die and gas hydraulic suspension for heavy-duty off-road vehicles. The company has a long history that goes back to 1872 when the company was founded. Today they are a part of the American holding company, Barnes Group Inc. They sell world leading products for tool & die with an export of 95% and around 50% share of the world market. With currently 350 employees located in Tranås, Sweden, the company’s revenue amounts to around 1 billion (SEK) in 2017.

Strömsholmen’s mission statement is as follows;
“To develop, produce, and sell products and services based on gas spring technology. The products and services provide superior value to the customer through innovative technical solutions, high quality, reliability and safety and are to be available globally.”
1.3 Barnes Group

Strömsholmen is since the year 1999 a part of the American holding company Barnes Group Inc, listed on the New York Stock Exchange. With companies in 60 locations all over the globe, Barnes Group has a total of around 5000 employees. Strömsholmen is part of the Barnes Industrial Branch specifically to NGP (Nitrogen gas products) as shown in Figure 2.

Figure 2. Barnes Group division where Strömsholmen is part of NGP (Strömsholmen AB, 2017).
2 Current situation

Strömsholmen has for many decades been highly successful with their products for tool & die. Although business in this area is flourishing more than ever, Strömsholmen are looking at other products to develop and other markets to explore. Eight years ago, they started developing a new kind of gas spring as a mean to still be able to expand and to find new markets. The new spring combines gas with oil to create a hydraulic hybrid suspension for use in heavy-duty off-road vehicles. Customers have been rushing to the buy button to get their hands on these hydraulic springs that are highly versatile, combining a long stroke with great damping. The thing that differentiates Strömsholmen’s hydraulic suspension from conventional damping is that you can receive a long stroke and at the same time hold up a lot of weight. This is not possible with a traditional coil spring combined with a so-called shock (a.k.a. strut), without having to make major compromises of its performance.

With a high demand for these Hydrops – Strömsholmens name for their gas hydraulic suspension products – from the start, Strömsholmen have had little time to optimize every part of the development process and the main focus has been on performance and customer satisfaction. In fact, the demand has been so high that Strömsholmen now have orders for the next 4-5 years if the production rate continues at the same pace. At this point, it is now catching up with them that a Design for X evaluation of the products life-cycle phases (manufacturing, assembly, and service etc.) is long overdue and would be of great value.

The left column in figure 3, show products that are part of Strömsholmen’s existing customers, the Tool & Die segment, while the right column is product categories with new customers. The Machine & Vehicle category is a growing area of new and existing products for new military customers. Barnes group, as the holding company of Strömsholmen, made in 2015 a strategic plan for the whole branch of NGP (Nitrogen gas products) – including Strömsholmen. In that plan, Barnes Group estimates that over 50% of the growth in 2016-2020 is forecasted to come from Machine & Vehicle (M&V). For the Suspension market/industry, they identified that there is an increased focus to prolong service life on military vehicles and that they

Figure 3. As part of Strömsholmen’s expansion strategy, this study will focus on top right corner, new products for new customers (Strömsholmen AB, 2017).
need to establish more contact with the military end user. They also state that for the military suspension customer, the performance and total vehicle cost are important to them and that their business is changing with more focus on “function$/S”’. They also express specifically for Hydrop suspension that a modular and simplified design with minimal customization could help to handle the demand for cost-effective safe military vehicles.

2.1 Problem Breakdown
Strömsholmen have explicitly expressed a need for design for assembly and manufacturing approaches within Hydrop at their R&D department. As the company grows and volume of products increases it becomes more important to design with these methods in mind. Custom solutions and taking the responsibility for the whole product life-cycle is an ambition at Strömsholmen since customer satisfaction is essential for their business. Being able to provide excellent service is, therefore, becoming increasingly important to the firm.

It is a real two-sided problem merged into one. On one side it is about being able of providing a service offer that exceeds customer expectations and gives Strömsholmen control and responsibility of the complete life-cycle. On the other hand, it is about providing products that are sustainable and long-lasting, with a great performance by designing for the whole product life-cycle. These two might seem far off from each other, but they really should go hand in hand. Trying to provide a service offering without taking product life-cycle activities into consideration, such as design for remanufacturing, DFRem, would aggravate the problems that come with an implementation. A service offering often includes a lot more control and responsibility for your own products. This could mean taking back products from customers after use, to recycle or reuse. If this step is anticipated and prepared for, the outcome can be greatly improved. And it is also the other way around. Why design for disassembly and remanufacturing if you completely lack control over your product as soon as it is sold, and you might not ever see it again? The incitement for design for disassembly, DF, design for serviceability, DFS, and design for remanufacturing is increased by the tenfold if it is known that the products would come back to you after a certain period in the customer's hands.

2.2 Problem Statements
The two-folded objective of the thesis are broken down into the following problem statements:

1. **Problem statement 1 - How can Strömsholmen move towards a more integrated product service offering for Hydrop?**
   a. How can a business model for a product service system for Hydrop be formulated?
   b. What services are fit for Strömsholmen to enable service growth?
   c. What distinctive resources and capabilities are needed to develop a successful product service system for Hydrop?

2. **Problem statement 2 - Can Hydrop be redesigned to be more valuable to Strömsholmen and their customers?**
   a. How can Hydrop be designed to lower the costs of assembly and service?
   b. How can Hydrop be designed to facilitate remanufacturing?
   c. How can efficiency in assembly and service for Hydrop benefit a product service system?
2.3 Hydrop - H5

Around 8 years ago, Strömsholmen started to deliver their gas hydraulic suspensions to customers around the world, to places such as Finland, Switzerland, and India. The suspension systems are made to fit heavy duty off-road vehicles, especially for army vehicles as shown in Figure 4. New models have been developed and existing products have been improved every year to accommodate customer needs and to increase performance. One of the latest Hydrops Strömsholmen developed is the H5, a designation consisting of other Hydrop products that all shares structure, components, and characteristics, the 5 in H5 stands for the capacity of 5 tonnes of force. Compared to traditional suspension where spring and damper are separate units, Hydrop has both functionality all-in-one — as schematically shown in Figure 5. Having a standardized platform allows Strömsholmen to offer customized products with variable features and functionality to their customers without having to make a whole new product. The H5’s is sold primarily to companies that builds AMV’s, armored military vehicles.

![Figure 4. Hydrop is a gas hydraulic suspension system for heavy-duty off-road vehicles (Strömsholmen AB, 2017).](image)

![Figure 5. The competitive advantage of hydrops lies in the compact all-in-one functionality. (Strömsholmen AB, 2017).](image)

When H5 was designed, the demands and requirements from customers were clear. The customers wanted reliable products and Strömsholmen wanted to deliver products that generated great profits. The designers trying to fulfill both the
customers and Strömsholmens own needs, therefore, designed the H5 to be a well-built, reliable product that is easy to assemble and that will last long. There were no pronounced requirements for the product needing to be easy to maintain, easy to disassemble or easy to repair, and since it on paper could last for a long time with a relatively inexpensive construction, those factors were never considered in a way they should.

This obviously results in a product tough to maintain with difficulties in disassembly. Strömsholmen performed a disassembly test of H5 with products that had not been used but were assembled only to utilize the test. Despite the H5’s being unused, the personnel experienced that the process of disassembly to be less fluent than hoped. The disassembling process gives wear and tear to the components and to the treatment of the surface. This is a result, in part, from a lack of correct tools and utilities that are made specifically for assembly and disassembly. The wear and tear also indicate concrete improvements could be made to product design.
3 Course of Action

To follow the thesis objective and answer the problem statements — the course of action is divided into five different phases:

1. **Planning phase**
   Beyond planning out the work, this phase consists of gathering initial information of the problem at hand with information handed from Strömsholmen supervisor. Resulting in the problem statements of the thesis.

2. **Literature Phase**
   In the second phase, the literature phase, we delved deep into literature and methods used during the data gathering phase.

3. **Data gathering phase**
   In this phase, semi-structured interviews were conducted with personnel at Strömsholmen to gather valuable information for a service growth strategy and understand what product service system logic is fit for Strömsholmen and Hydrop. Beyond interviews, the disassembly of eight Hydrop H5 was observed. Later, examinations were performed on drawings and product service/disassembly guidelines. DFX analysis was performed on different life-cycle phases of Hydrop. These included a DFA analysis to gather theoretical minimum part count of products and other useful information. DFS, DFD, and DFRem acted as tools to assess the maintenance and remanufacturing possibilities of Hydrop. Together with employees at Strömsholmen, with great internal knowledge, a workshop was held to gather suggestions for ideas and improvement of Hydrop in trying to answer: "What services can increase the customer’s perceived value of the product?". The participants used Brainwriting in order to come up with service ideas and the PSS layer method to visually show how they could be implemented.

4. **Idea phase**
   In the idea phase, we took the data from DFX analysis and presented possible changes to Hydrop H5. Based on the ideas from the workshop we presented a Business Model Canvas for how Hydrop could be part of a product service system with outcome-based service contracts.

5. **Termination phase**
   The last phase results were assembled, discussed and summarizes along with a conclusions and future recommendations of the work.

3.1 Literature Study and the Method of Analysis
The literature study was conducted by looking at related course literature from Linköping University courses in Industrial service development and Integrated product and service engineering. Extending from that, searches through databases, such as ScienceDirect and Business source premier, provided by LiU Library added additional articles and books. Books and course literature that then was borrowed from the campus library. Some of the search words used where PSS, Product Service Systems, IPSO, Integrated Product Service Offering, Servitization, DFX, DFM, DFA, DFS, DFD, DFRem.
Based on the reference lists of articles found, authors and search words could be continuously added throughout the literature phase. Literature choice was also largely influenced by thesis supervisor and LiU Associate professor Erik Sundin — who has written extensively on the topic of product service systems.

In order to ensure the quality of this study in regard to validity and reliability, the method of triangulation was used in the literature study by gathering information on different but overlapping theories which Rankin (2016) means helps to get a more nuanced standpoint and increase credibility.

### 3.2 The Interviews

*Table 1. Examples of semi-structured interview questions.*

<table>
<thead>
<tr>
<th>Division</th>
<th>Number of people</th>
<th>Example questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production support</td>
<td>1</td>
<td><em>Is maintenance considered when developing products?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>What are your thoughts about reusing components and remanufacturing?</em></td>
</tr>
<tr>
<td>Aftermarket</td>
<td>1</td>
<td><em>Do you view service as a necessary evil?</em></td>
</tr>
<tr>
<td>CEO, Sales/Marketing</td>
<td>5</td>
<td><em>How can service help us to create and capture more value from our customer relationships?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Can our salespeople sell value-added services?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Do they have the skills and profiles needed for selling service?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Do we have a service strategy in place, and how well are people aligned with it?</em></td>
</tr>
<tr>
<td>R&amp;D</td>
<td>4</td>
<td><em>In what way is DFA thinking part of the design process today?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>What is prioritized the most in R&amp;D? Should designs be cost-effective, fast to assemble or is it the function/performance?</em></td>
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</table>

Key questions about the imperative for product service systems was answered during interviews (some example questions can be seen in table 1). This was to get a solid assessment of the current situation at Strömsholmen as a first step to answer the thesis problem statements. The interviews were conducted with people from production, sales/marketing, aftermarket, R&D and the CEO at Strömsholmen — eleven people in total. The reason for the interviews being from a variety of functions at the company was to gather as much internal knowledge as possible. They include people working in the production process of manufacturing and assembly, people at a
strategic level, people working specifically on Hydrop, people working in sales close to customers as well as people from R&D close to products. This resulted in receiving a nuanced perspective on the issues, see Table 1. Many of the questions were inspired by Kowalkoski and Ulaga (2017) while others were more specific to Hydrop. The questions used for each respondent was picked out beforehand from a pool of questions. The interviews were held in a semi-structured manner and recorded. Pharm (2014) argues semi-structured interviews are great for qualitatively gather data. That is because adopting a qualitative methodology allows for fine-tuning of pre-conceived notions, extrapolate the thought process as well as — analyze and estimate the issues from an in-depth perspective (Pharm, 2014).

3.3 Disassembly Observations
A demo disassembly of eight Hydrop H5 suspension systems was observed with notes taken from the procedure. Meetings were conducted with people part of the team responsible for the demo. Following the observations, the disassembly observations, drawings and disassembly guidelines were examined.

3.4 Design for X Methods
A few different DFX methods was used to understand the different stages of the life-cycle of a product. The methods were used mostly to help answer the second problem statement. (The DFX methods are also theories more extensively covered in the theoretical framework part of the report.)

Design for assembly (DFA). Design for assembly is a well-developed method made popular by Boothroyd and Dewhurst (2011) in the 1980s. Since then it has been used by countless companies, both industry giants and small establishments. The method was used to investigate and evaluate in what way Hydrop and specifically H5 can be optimized in parts count and how efficiency in assembly time can be increased.

Design for disassembly (DFD). Design for disassembly is compared to DFA not as well-known and in comparison, considered as quite new to the industry with introduction around the start of the twenty-first century (Das & Naik, 2002). Unlike DFA, which end results can be defined in a design document, DFD contains unknown parameters such as the condition of the components that are being disassembled since they often been used. However, products designed for disassembly are considered to be less prone to damage during disassembly leading to lower material for replacement parts (Guide, 2000). The method was be applied to support other features such as remanufacturing, maintainability and repair.

Design for serviceability (DFS). Design for serviceability is about maintenance and repair of products. If designing with certain rules in mind it can be determined how maintenance should be conducted and to what extent (Taylor, 2014a). The theory helped with understanding in what way products can be adapted for easier maintenance and how products at fault easily could enable repair.

Design for remanufacturing (DFRem). Design for remanufacturing is about the idea of restoring used products and turn them into a “good as new” condition (Steinhilper, 1998). Remanufacturing is considered as the ultimate way of recycling and called a win-win-win situation with customers paying less, higher earning for remanufacturing companies and it benefits the environment (Sundin & Dunbäck, 2013). The method acts as the connector between the other DFX methods and was vital to complete the life-cycle for H5.
3.5 Workshop on Service Innovation

A one-hour workshop was conducted with four employees at Strömsholmen representing R&D, after-market sales, and production. The focus of the workshop was to brainstorm ideas for service innovation and how to grow through new product-service combinations, in particular towards the suspension customer and military end user. The participants were faced with the problem statement: “What services can increase the customer's perceived value of the product”. The workshop was useful not only for creating a sense of ownership and acceptance of new ideas but also create familiarity with methods for service innovation. Methods used in the workshop were:

**Brainwriting.** An interactive brainwriting session takes roughly 10-15 minutes where the group writes down a few new service ideas in silence on sticky notes and then each participant passed their ideas on to someone else who reads the ideas and adds new ones (Wilson, 2013). This method not only produces more ideas but reduced the amount of extraneous talk that happens during regular brainstorming, which takes time away from idea generation (Wilson, 2013). The workshop was conducted in this manner and after performing the session, the workshop moved over to the PSS Layer method.

**PSS Layer Method.** The PSS Layers method is a way to conceptually design new product service systems using a set of class elements layered on top of each other as seen in Figure 6. It proceeds stepwise and enables a structured documentation of a possible future PSS (Müller, et al., 2009). The top part of the model is the customer view with needs and values as seen in Figure 6. After probing the participants for the needs and values of suspension customers and end users, they discuss and pick the best idea from the brainwriting session and map it out on the PSS layers — tracing back the classes of the design layer as seen in Figure 6. Müller, et al. (2009) argues this method is valid not only for developing a new PSS (starting from customer needs) but also transforming a product into a PSS. Using this method helped the participants to visualize the ideas that came up in the brainwriting session. The layers of the PSS consisted of the following:
Course of Action

- Needs
  - What is the customer needs? (Solution independent e.g. “High vehicle reliability”.)
- Value
  - What does the customer perceive valuable?
- Benefits in terms of the customer. (E.g. monetary benefit or saved time.)
- Deliverables
  - Life-cycle activities
    - Process composed of life-cycle activities connecting “resources” as stakeholders, core products etc. with deliverables.
- Actors
  - Actors, stakeholders, business units, or even software agents involved in life-cycle activities.
- Core Products
  - Core products which have to be developed (and manufactured): Products which will be handed out to customers and products which remain in the PSS providers network and ownership.
- Periphery
  - Backstage equipment, which is not directly visible to the customer and system periphery (e.g. support equipment, technical periphery, tools, infrastructure, or PSS execution systems).
- Contract
  - Conditions which have to be mentioned or expressed by contract.
- Finance
  - How can the PSS be financed? What payment model for the customer?
- Optional Layers
  - Layers that can be added as e.g. “sustainability”, “cost” etc.
To practice using the PSS layer method also probes participant for “thinking service” when developing new products.
3.6 **Business Model Canvas**

The business model canvas (BMC) as presented by Osterwalder and Pigneur (2010) is a tool to describe and visualize existing or new business models in a shared language. Therefore, the visual business model canvas was used to describe the result of a new business model for Hydrop H5 as part of a PSS.

3.7 **Limitations**

We were limited in the amount of material given by Strömsholmen. The customers for Hydrop are military which results in a high level of confidentiality. The effect of this is that not all details of drawings or product functions can be shown in this thesis.

3.8 **Delimitations**

DFM, design for manufacturing, was to some extent limited in this research since the vast majority of parts are brought in from suppliers for the gas hydraulic suspension category of products. The guidelines for DFM was considered but not specifically the exact costs for components. The DFA, design for assembly was limited in use by calculating a theoretical minimum part analysis and not to estimate assembly time or costs. Even though the result of this study may be implementable to a wide range of product categories at Strömsholmen, the focus on this study was applied to gas hydraulic suspension systems and specifically the product family H5 for armored military vehicles.
4 Theoretical Framework

The theoretical framework chapter includes a definition of service, why B2B manufactures should seek service-led growth and the concept of hybrid offerings. The framework goes further into examining service strategy and how to build a service portfolio. How to design for Product Service Systems (PSS) with a life-cycle perspective is reviewed and the tools and methods used for designing for the life-cycle phases. The tools are — design for manufacturing, design for assembly, design for disassembly, design for serviceability and design for remanufacturing. Ending with an analytical model condensing the perspectives to a holistic one. The topics covered in the theoretical framework are:

- Services Combined with Products — Definitions and Terminologies
- Why Seek Service-led Growth?
- Product Service System — Combining Goods and Services Successfully
- Is Service Strategy Aligned with Corporate Goals?
- A Roadmap for B2B Service Growth and Building a Service Portfolio
- Design for Product Service System with a Life-cycle Perspective
- Design for Manufacturing
- Design for Assembly
- Design for Disassembly
- Design for Serviceability
- Design for Remanufacturing
- Analytical Model of Theoretical Framework

4.1 Services Combined with Products — Definitions and Terminologies

According to Grönroos (2013), there are at least two major definitions of service:

1. Service as an activity (e.g. restaurant service, repair, maintenance, transportation)
2. Service as a perspective on business and marketing (regardless of whether the core of the business is a physical product (good) or a service activity)

To clarify even further, service as a perspective is further defined from the firm’s perspective with a provider service logic (Grönroos, 2013):

“Service is to facilitate and support someone’s practices (process, activities; physical, mental) in a way that contributes to this person’s or organization’s value creation.”

– Christian Grönroos, professor of service and relationship marketing (2013)

The research on services combined with manufactured products has been expressed in many different ways, leading to some confusion through academia and industry about the terms used to describe it. From design research disciplines, several groups use concepts named such as: SPE (Service/Product Engineering), IPSE (Integrated Product and Service Engineering), or functional products (Sakao, et al., 2009, p. 770) basically pointing at the design processes of developing services and products. From another part of academia, industrial service development, groups use names such as such as IPSO (Integrated Products and Service Offering), hybrid offerings and
functional sales focusing more on the business models of these offerings (Kowalkowski & Ulaga, 2017). Product Service Systems (PSS) is also a concept that integrates products and services in one scope with a life-cycle perspective — predominantly used in academia but less so in the industry (Sundin, 2009). Nevertheless, these terms have nearly equivalent meaning — that is — integrating products and services into new solutions. Solutions that are attracting attention from industry (Müller, et al., 2009).

From the customer’s perspective, Grönroos (2013) argues that customers only consume products like services, because it helps them in their activities or processes — they merely see providers of products as service providers. What does this mean for manufacturers that mostly point to technical aspects of products and less on functional aspects around product performance and delivery (Grönroos, 2013)? What happens when firms don’t see themselves as service providers? Grönroos (2013) answers that operating as a service business is a strategic choice and a strategy most product-centric manufacturers can seek out.

4.2 Why Seek Service-led Growth?

According to Kowalkowski and Ulaga (2017), there are two fundamental reasons why goods-centric firms seek service-led growth. Companies either pursue service-growth strategies from a defensive stance in a move to protect their existing business from competitors, or they view services as a proactive weapon to actively move to acquire new customers, access greater volumes and bigger margins. The authors emphasize that these moves are fueled by some fundamental trends:

Saturated and commoditized markets. A growing number of industries are experiencing a saturated demand for their core products meaning it is harder to grow their installed base further. They go on to say that capturing greater revenues and profits through services becomes particularly important in situations where the number of new units sold is by far outnumbered by the installed base of goods sold.

Customer pressure. As many customers reduce their supplier base, they expect more from their suppliers and want much more to pay for performance instead of buying goods and services.

Exploiting product and technology expertise. Another reason to move to service-led growth is by internally exploit the engineering and technology expertise available. Typically, when a manufacturer has a high-performing product, services can become a strategic weapon to unlock the product’s value.

Capturing customer relationship value. By its very nature, service requires more and closer customer interaction, which helps to better understand customer needs. The interest may also lie in enlarging the lifetime value of a customer, which represents the net earnings the company makes from the customer throughout the course of the relationship. This is equal to the difference between annual profits streams minus costs of retaining and developing the customer relationship.

Opening new market opportunities. This move is about venturing into entirely new service business models and offering new value constellations. This is the internal factor that has the most disruptive effect on the company and the rules of business in the industry.
4.3 Product Service System — Combining Goods and Services Successfully

Extensive literature touches on the subject of pure service players in a consumer market setting, such as the airline industry, financial services, hospitality, and retailing. Less has been written about what is needed for a traditional manufacturer to move into service and customer solutions in B2B (Ulaga & Reinartz, 2011). This goes in on the domain of hybrid offerings—products and services combined into innovative offerings (Shankar, et al., 2009, p. 95). An alternative expression for product service systems in the literature. Nonetheless, you could ask: which particular strengths in operations, product development, and marketing can a manufacturer leverage particularly well for hybrid offerings? What unique opportunities exist that pure service players cannot access? Ulaga and Reinartz (2011) argue that there are only a few concrete resources and capabilities manufacturers can leverage to build hybrid offerings (as seen in Figure 7), where a few can be added or subtracted to fit a specific manufacturer.

![Diagram](image_url)

Figure 7. Manufacturer-Specific Resources and Capabilities for Successful Hybrid Offerings adapted from Ulaga and Reinartz, (2011)
The first resource for service growth, *installed base product usage and process data*, is the most strategic asset held by manufacturers today. This can be both in terms of sensors collecting data remotely and in real time on how the product is used or if it is holding up. But it can also be in terms of products that are coming back for repair which provides valuable information on how the products perform out with the customer. *Product development and manufacturing assets* are also extremely valuable resources linked to R&D, design, and production processes. These may be tangible (such as components, machines or tools) or intangible (like patented technologies and production licenses). Kowalkowski & Ulaga argues (2017) that other valuable resources are *Product Salesforce and distribution network and field service organization*. Nonetheless, Ulaga and Reinartz (2011) argue that each company needs to assess which resources are most strategic specifically for them — to leverage for service growth.

Ulaga and Reinartz (2011) argue that manufacturers not only need to leverage resources but develop capabilities (as seen in the second column of Figure 7). *Service related data processing and interpretation capability* is one such capability that is developing skills to turn product use data into a source of revenue or new opportunities. Resulting in a cost-benefit in terms of productivity enchantments. To understand what data to collect Kowalkowski & Ulaga argues (2017) that a question must be asked of which key performance metrics truly matter to customers? Ulaga and Reinartz (2011) state that another capability manufacturers’ can leverage is *Design-to-service capability* — that is about incorporating service thinking as early as possible in a firm’s innovation process. They argue that by overly focusing on product innovation processes, managers to often miss out on opportunities for unlocking service revenue and profit potentials. Product and service innovation must interact synergistically for value creation rather than in a merely additive manner. Kowalkowski & Ulaga (2017) add that if manufacturers can leverage mentioned resources into these capabilities this will lead to either a *differentiation advantage* or cost *leadership advantage* (see Figure 7).
4.4 Is Service Strategy Aligned with Corporate Goals?

Service strategy touches on the way firms define their business (Kowalkowski & Ulaga, 2017, p. 64). Kowalkowski and Ulaga (2017) argue that business leaders must constantly question the relevance of their current business model. Will the current business model allow the integration of a service business? Service-led growth by manufacturers is frequently led by a discussion in terms of a product-service transition (Kowalkowski & Ulaga, 2017, p. 65). Rudimentary, the increased importance of services can be illustrated as a move from a product firm to a service firm. As firms move along the product-service spectrum in Fel! Hittar inte referenskälla., the relative importance of services increases. Executives need to know why and how to expand their service business, where they are now and what the target position should be and when not to go further (Kowalkowski & Ulaga, 2017, p. 65).

The key role for senior management becomes to review the manufacturer's mission statement and positioning of the firm to see if the goals of service growth are stated or need revision (Kowalkowski & Ulaga, 2017, p. 71). The firm's mission statement is the definition of the purpose of the organization and the ambition of what it seeks to achieve to ensure its survival and long-term growth (Kowalkowski & Ulaga, 2017, p. 72). But what are the effects of pursuing services strategically? Fang, Palmatier & Steenkamp (2008) measured the effect of service transition strategies on firm value over a wide range of U.S. industrial firms. They found that the effects on firm value become pronounced only after the level of service sales reaches a critical mass, which averages approximately 20%–30% of total firm sales. In other words, initial service investment may not at first be profitable, so the negative effects of service transition strategies are strongest at low levels of service sales and diminish as the service ratio increases.

Research has shown that many manufacturers have grown their service business, not through service transition in the literal sense but rather trough service infusion (Kowalkowski & Ulaga, 2017, p. 68). Extending the firms offering rather than moving away from product to service sales (Kowalkowski & Ulaga, 2017, p. 68). Grönroos (2015, p. 465) takes a much stronger position and argues that if manufacturers want to truly adopt a service perspective, a servitization or service infusion approach, won’t work. He argues it is not enough to gradually add more service activities to the core offering, which remains physical product-based. Instead, Grönroos (2015, p. 465) reasons that manufacturers need to take an overall strategy that is service-based, and the core of the offering has to be a value-creating support to customers, not a physical product or any other type of resource. In the offering,
product and service activities have to merge into an integrated process, which aims at supporting the customer's process and eventually their business processes (Grönroos, 2015, p. 465). Grönroos (2015, p. 465) argues that the benefits for manufacturers to take on a service business are that the manufacturer has potential to help their customers serve their customer in a more efficient and effective, and therefore probably more profitable, manner.

Should all these changes be made dramatically or incremental? What are the most challenging aspects of change? Is service strategy aligned with corporate goals? These types of questions Kalkowski and Ulaga (2017) claims must be debated and resolved before setting a service strategy and venturing into the deployment of a service portfolio.
4.5 A Roadmap for B2B Service Growth and Building a Service Portfolio

Many classification schemes have been suggested for services, predominantly in a consumer market context. However, Ulaga & Reinartz (2011) argues that the classification of industrial services has not received the same level of attention as consumer services. The authors originally proposed a classification scheme for how industrial services can be classified. Building on that Kowalkowski & Ulaga (2017) adopted the scheme and proposed a service growth roadmap for B2B industrial manufacturers — for building a service portfolio as seen in Fel! Hittar inte referenskälla.. They argue that with an understanding of critical resources, capabilities and what to set as a service strategy, a company can then decide how to build its service portfolio over time using the roadmap (Kowalkowski & Ulaga, 2017, p. 97).

When discussing service-led growth the classification framework can help to better understand which types of services a firm can develop and how it should grow its services over time in a systematic manner (Kowalkowski & Ulaga, 2017, p. 33). The framework is built on two fundamental dimensions. The first dimension distinguishes between services oriented towards the supplier’s product (Such as repairing a...
Theoretical Framework

machine) and services directed to the customer’s activities and processes. This dimension looks to who is the service recipient? The second dimension relates to the nature of the customers promise made by service, in other words, the value proposition. Is the value proposition based on a promise to perform an input-based deed? Or, on the contrary, is the value to promise a level of output-based performance? Based on these two dimensions, four different types of service categories form a framework (see Fel! Hittar inte referenskälla.). Ulaga & Reinartz (2011) argues that these four categories differ fundamentally in key resources and capabilities needed to deploy product service offerings.

**Product Lifecycle Services (PLS).** Product Lifecycle Services represent a natural starting point for growing a company’s services portfolio. Even deeply product-centric firms to some extent must ensure the provision of some fundamental services. (Kowalkowski & Ulaga, 2017, p. 98) These services refer to the range of services that facilitate the access of to the manufacturer's goods ensure its function during the product lifecycle, including basic service of hardware (Kowalkowski & Ulaga, 2017, p. 34). However, in a study performed by Ulaga & Reinartz (2011), they found that managers complained that the numbers of customers willing to pay for such services were low with the reason being that they found it difficult to differentiate PLS. Nevertheless, managers saw that PLS played a key role in establishing their reputation as a competent service provider and building trust. To succeed in this category Ulaga & Reinartz (2011) argue that manufacturers need to meet customers’ basic expectations in the most cost-efficient manner, using highly standardized services. Therefore, a manufacturer’s skills in deploying the product-service offering emerged as the primary distinctive capability required for mastering PLS. In addition, managers that allowed the pursuit to redesign equipment or components to minimize PLS production and delivery costs also developed distinct capabilities.

**Asset Efficiency Services (AES).** Asset Efficiency Services are services where the fundamental nature of the value proposition has moved towards an output-based performance offer in using our products. With PLS a manufacturer promises a deed (i.e. “we fix the in-flight entertainment system when it breaks”), but with AES, they go one step further and commit to performance related to asset productivity (i.e., “we guarantee availability of 98.5% of video screens up and running in an aircraft”). To grow PLS to AES follows a natural transition many companies take while remaining in a secure comfort of their own products (Kowalkowski & Ulaga, 2017, p. 100). Example of technologies used to facilitate these services are predictive maintenance with products equipped with sensors that gather usage data. Data that can be sold as a service to a customer or facilitate product improvement long term. By investing in products underlying AES, acquiring and safeguarding product usage, manufacturers can develop an ability to predict product failure rates, a capability Ulaga & Reinartz (2011) argue is crucial to be successful with AES. Setting the price for AES may even require that a manufacturer accepts providing services at a loss for a certain amount of time for the sake of acquiring strategic data of product use that will compress its own learning curve (Kowalkowski & Ulaga, 2017, p. 137). However, Ulaga & Reinartz (2011) maintains that since AES is far less standardized than regular PLS and the focus shifts from a cost-plus price setting logic to a value-based logic — That allows manufacturers to raise customers’ willingness to pay for AES. Provided the manufacturer can persuasively communicate the potential in form of productivity gains, cost savings or risk mitigation.
**Process Support Services (PSS).** Process Support Services is another service growth trajectory that focuses more on a customer’s process than a specific product. The service portfolio is grown by getting more deeply involved in customer’s processes without taking full responsibility for the output of that process (Kowalkowski & Ulaga, 2017, p. 100). Rather, the supplier assists the customer in performing that process better. Typical examples are auditing, consulting or training services. Ulaga & Reinartz (2011) discusses that the value proposition focused on leveraging the supplier’s specialized competences is to help customers optimize processes, or specific process elements, in their operations. In other words, performing specific, process-oriented deeds to assist customers in what they had to do. In Ulaga & Reinartz (2011) study they found customers’ willingness to pay for process support services tended to be high and that manufacturers could bill customers according to the time and resources needed to provide the service. They argue that these services required reaching different people in the customer organization and using different sales arguments. Kowalkoski & Ulaga (2017) also argues that this category is benefiting from enhanced data analytical resources and skills from predictive maintenance.

**Process Delegation Services (PDS).** Process Delegation Services is a much more uncommon venture for manufacturers to take which involves both shifting the value proposition to an output-based performance value while also taking responsibility for a specific customer process. Kowalkowski & Ulaga, (2017. p. 101) argue however that company only can provide PDS once a manufacturer has established a solid position within the three other service categories.

Practical implications of growing product service offering reveal that many manufacturers still fail to recognize the strategic value of their installed product base and the insights from data it can provide (Ulaga & Reinartz, 2011). The innovation processes of leading manufacturers in Ulaga & Reinartz (2011) research show that many modern firms do not “think service” from the outset. They have not incentivized or trained their product development staff, and do not include a service imperative as a key objective in their innovation specifications. Ulaga & Reinartz (2011) determines that (re)designing products (with product service system in mind) would enable the manufacturer to adapt their integrated product service offering and take their business to new levels.
4.6 Design for Product Service System with a Life-cycle Perspective

Research has shown that when it comes to designing for product service systems (PSS) a key factor is to design from a life-cycle perspective (Sundin 2007) (Muto 2015). Life-cycle, according to Sundin (2009), refers to the progress of bringing a product from raw material, through production, and use, to its final disposal and/or recycling of material, parts or whole assembly as illustrated in Fig. 10. The life-cycle perspective is increasingly important as more and more companies see the benefits of controlling a larger share of the product value chain thus avoiding sub-optimizing any specific life-cycle phase (Sundin, 2009). Findings from research have shown that considering the product life-cycle phases, specifically manufacturing, assembly, delivery, use, and maintenance have led to design improvements that deal with accessibility of parts and components during repairs and remanufacturing operations. Improvements and adaptations that could greatly reduce the need and cost of maintenance, repair and remanufacturing (Sundin, et al., 2009).

![Life-cycle Diagram](image)

*Figure 10. The physical product life-cycle adopted from Sundin (Chapter 2, 2009).*

Having a life-cycle perspective on combined services and goods mean that life-cycle considerations must be considered both for physical products used in PSS and the services that are used during and between contract times (Sundin, et al., 2009). Sandborn et al. (2016) argue that outcome-based contracts that pay for effectiveness and penalize performance shortcomings have been introduced to incentivize cost reduction efforts on the contractor side of product service systems. Arguing that these contracts are being acquired in healthcare, energy and military systems and allow customers to pay only for the specific outcomes achieved — e.g., availability —
rather than the workmanship and products delivered (Sandborn, et al., 2016). In general, the PSS approaches seem to work well for manufacturers if any of the following conditions apply (Tukker & Tischer, 2006):

- Products with high costs to operate and/or maintain.
- Complex products that require special competences to design, operate, manage and/or maintain.
- Products with considerable consequences or costs if not used correctly or appropriately.
- Products where operational failure or downtime is not tolerated.
- Products with long life.
- Products with only a few major customers on the market.

The physical products of the PSS can be adapted in various ways for the product life-cycle according to the umbrella term of DFX methodologies (Sundin, et al., 2009). There are many different engineering methods and tools that would result in adaptation for manufacturing, delivery, usage, maintenance, disassembly, reassembly, testing, recycling and/or re-manufacturing (Sundin, et al., 2009). The following paragraphs describe more deeply the tools needed in the product life-cycle phases — manufacturing, assembly, disassembly, service and remanufacturing.
4.6.1 Design for Manufacturing

The DFM methodology, as presented by Boothroyd, Dewhurst & Knight in their book *Product design for manufacture and assembly* (2011) present a set of design guidelines as well as making cost estimations for the manufacturing of parts. Looking especially at the design for machining of rotational components, there is a summary of main points a designer should keep in mind when considering the design of machined components (Boothroyd, et al., 2011, p. 300).

**Standardization**

1. Utilize standard components as much as possible
2. Preshape the workpiece, if appropriate, by casting, forging, welding, and so on.
3. Utilize standard pre-shaped workpieces, if possible.
4. Employ standard machined features wherever possible.

**Raw material**

5. Choose raw materials that would result in minimum component cost (including the cost of production and cost of raw material).

**Design of rotational components**

7. Try to ensure that cylindrical surfaces are concentric, and plane surfaces are normal to the component axis.
8. Try to ensure that the diameters of external features increase from the exposed face of the workpiece.
9. Try to ensure that the diameters of internal features decrease from the exposed face of the workpiece.
10. For internal corners of the component, specify radii equal to the radius of standard rounded tool corner.
11. Avoid internal features for long components.
12. Avoid components with very large or very small L/D ratios.

**Accuracy and surface finish**

13. Specify the widest tolerances and the roughest surface that would give the required performance for operating surfaces.
14. Ensure that surfaces to be finished-ground are raised and never intersect to form internal corners.

There is also supportive software that can help designers apply these guidelines to a specific CAD model and estimate costs. Examples are Boothroyd and Dewhurst DFMA Software⁠¹ and CAD software like Solidworks² that have design for manufacturability built in.

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¹To read more about Boothroyd and Dewhurst Design for Manufacturing and Assembly Software visit: http://www.dfma.com/software/dfma.asp
Design for machining is a method within design for manufacturing focusing on designing to make the machining process on a component as optimized as possible. Machining is seen as a wasteful process and many engineers deem that the main objective when designing components should be to try to avoid machining entirely (Boothroyd, et al., 2011). This is in the immediate future considered to be highly unlikely with machining being as well-established as it is today. The tendency is, however, leaning towards products being “near net shape” before the machining process in order to avoid it as much as possible. It is possible according to Boothroyd et al. (2011) to make cost estimations on machined components if you know — material cost, machine loading and unloading, handling between machines, machining costs, tool replacement costs and other machine data. However, in early design stages, this information might not be available. Boothroyd et al. (2011) says however that it is possible to make approximate cost estimations based on component size.

As seen in Figure 11, the cost of machining decreases and becomes less of the total cost of a component as the finished volume increases. Simply put, Boothroyd et al. (2011) mean that for average to large sized workpieces, the machining cost is mostly determined by the cost of the original workpiece or material. But the cost per unit volume increases rapidly for small components. This is because nonproductive times do not reduce in proportion to the smaller component size and the surface area per unit volume to be finish-machined is higher for smaller components.

Figure 11. Design for Machining, adapted from Boothroyd (2011, p. 323).

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To read more about Solidworks CAD software including Design for Manufacturability visit: http://www.solidworks.com/sw/products/3d-cad/design-for-manufacturability.htm
4.6.2 Design for Assembly

The DFA methodology, as also presented by Boothroyd et al. (2011), is a systematic procedure for analyzing a proposed design. It acts as a guide for product designers to make the assembly process more effective and less expensive with fewer parts leading to more reliable products. Fewer parts mean faster and more accurate assembly and a reduced inventory of different components. For this reason, it is given that few, more complex components are often preferred over many, simple parts (Boothroyd, et al., 2011).

The method provides three criteria for each part of an assembly that must be examined as it is added to the product during assembly.

1. During the operation of the product, does the part move relative to all other parts already assembled. Only gross motion should be considered—small motions that can be accommodated by integral elastic elements, for example, are not sufficient for a positive answer.

2. Must the part be of a different material or be isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable.

3. Must the part be separated from all other parts already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible?

Boothroyd et al. (2011) further explain that application of these criteria would now be applied to the original design and analyzed to get to a theoretical minimum part count. It is now necessary for the designer or design team to justify the existence of those parts that did not satisfy the criteria. Justification may arise from practical, technical or economic considerations. (Boothroyd, et al., 2011)

Company leaders wanting to use DFA will most likely face designers that have many excuses for not implementing DFA in their own processes and products (Boothroyd, et al., 2011). The most common one is that designers claim that they are not given enough time to carry out a DFA. Another excuse is called the ugly baby syndrome - designers won’t admit that their products are at fault or could be improved, they won’t realize that their design is not the best. There is also the belief that performing a DFA on a product with an already low assembly cost compared to other costs is unnecessary. However, Boothroyd et al. (2011) studies suggest, that performing a DFA analysis will possibly also impact the ways of manufacturing and how many parts there is, resulting in a lower overall cost.

Some general guidelines for applying DFA for manual assembly have through experience been developed in order to give designers some simple rules to follow. They are divided between the handling of parts and the insertion and fastening.
Design guidelines from Boothroyd (2011, p. 74) for part handling is as following:

1. Design parts that have an end-to-end symmetry and rotational symmetry about the axis of insertion. If this cannot be achieved, try to design parts having maximum possible symmetry.
2. Design parts that, in those instances where the part cannot be made symmetric, are obviously asymmetric.
3. Provide features that prevent jamming of parts that tend to nest or stack when stored in bulk.
4. Avoid features that allow tangling of parts when stored in bulk.
5. Avoid parts that stick together or are slippery, delicate, flexible, very small or very large, or that are hazardous to the handler.

Design guidelines for insertion and fastening from Boothroyd (2011, p. 74-78):

1. Design so that there is little or no resistance to insertion and provide chamfers to guide the insertion of two mating parts. Generous clearance should be provided, but care must be taken to avoid clearances that result in a tendency for parts to jam or hang-up during insertion.
2. Standardize by using common parts, processes, and methods across all models and even across product lines to permit the use of higher volume processes that normally result in lower product cost.
3. Use pyramid assembly – provide for progressive assembly about one axis of reference. In general, it is best to assemble from above.
4. Avoid, where possible, the necessity for holding parts down to maintain their orientation during manipulation of the subassembly or during the placement of another part. If holding down is required, then try to design so that the part is secured as soon as possible after it has been inserted.
5. Design so that a part is located before it is released. A potential source of problems arises from a part being placed where, due to design constraints, it must be released before it is positively located in the assembly. Under these circumstances, reliance is placed on the trajectory of the part being sufficiently repeatable to locate it consistently.
6. When common mechanical fasteners are used, the following sequence indicates the relative cost of different fastening processes, listed in the order of increasing manual assembly cost.
   a. Snap fitting
   b. Plastic bending
   c. Riveting
   d. Screw fastening
7. Avoid the need to reposition the partially completed assembly in the fixture.
4.6.3 Design for Disassembly

An approach that is necessary to consider within a life-cycle perspective is design for disassembly, DFD. Many companies see disassembly as an unnecessary evil that is time-consuming with a lot of manual work required. Instead, it should be looked upon as a method of great value that gives the chance to obtain and reuse complex and expensive components and to retrieve information about the use of a product. It helps the provider to understand how the customers use their products and how to make them more sustainable and better performing.

Design for disassembly needs to be considered from the start of development process much like DFA. Instead of compromising DFD to mind for DFA and trying to avoid conflicts, they need to be thought as equally important, although assembly often is considered to be the more time consuming and expensive process (Galantucci, et al., 2004). One constraint concerning disassembly and remanufacturing is that not all parts of a product can be retrieved with its original state intact, in other words not all parts can be remanufactured. A common misconception when discussing DFD is the thought that disassembly of the whole product is required. This is not correct. The vital thing is often to retrieve the so-called cores — the most expensive parts with the most valuable components. This saves time and eliminates unnecessary procedures and possible errors. An important thing to realize when wanting to retrieve the cores is that there is always more than one route for disassembly (Takeuchi & Saitou, 2008). This needs to be thoughtfully considered in order to find the optimal, shortest route and not just follow the first instinct. This is far from an easy task though and combined with DFA it is a real challenge.

DFD can in some cases be considered to be in conflict with DFA (Soh, et al., 2016). Some designs made for assembly can lead to complications in disassembly. Less, more complex parts, are often the outcome from a DFA which tend to make maintenance and upgrading, processes that require disassembly, more difficult with reduced part accessibility (Soh, et al., 2016). A good way of thinking when combining the two theories is that DFA always should be applied to every part while DFD only should be applied to the parts necessary, in order to avoid conflicts as much as possible. It is therefore important to early on identify the core of a product, and the best possible route for retrieving it, to make interference with the DFA minimized. In addition, products not designed for disassembly often leads to a higher risk of damaging components and to a more expensive process (Guide, 2000).
To determine the optimized route for disassembly and retrieval of the core in the product, a process flow can be followed in an iterative manner, see Figure 12 below (Soh, et al., 2016). The first step of all is to locate a fastener with a degree of freedom (DOF), and then determine if the fastener interferes with another part during removal. If that is the case, another fastener will be tested similarly. All parts that will gain one or more DOF when a fastener is removed will be evaluated in the same way as the fasteners. Parts that do not interfere with other parts or require excessive force to loosen will lead be removed, and then the process is repeated (Soh, et al., 2016).

![Figure 12 - Process flow to determine feasible disassembly sequences (Soh, et al., 2016)](image)

When discussing DFD, it can focus on either remanufacturing or recycling, or both. What the main difference is when focusing on recycling is that the wear and tear on the product during disassembly is not prioritized, and damage to components are not necessarily being avoided (Soh, et al., 2016). When focusing on remanufacturing, the parts that are disassembled for reuse needs to be handled with great care and this obviously gives impact to the disassembly process. When concerning disassembly for remanufacturing, a combination of the two is the most common, since it is more often than not that every component cannot be used again after disassembly and is instead recycled (Soh, et al., 2016).

When comparing recycling and remanufacturing, recycle is the far more common one of the two. This is thought to be due to the scares research within remanufacturing, leading to a lack of knowledge among designers. Indications show that recycling is stealing the designers focus from remanufacturing, although the most value both environmentally and economically can be found within design for remanufacturing (Ishii, 1998). Remanufacturing comes with more uncertainties and risks compared to the more straightforward method of recycling, another factor resulting in designer being more hesitant to the approach.
4.6.4 Design for Serviceability

Another method that is on par with design for remanufacturing is design for serviceability, which is about designing for maintainability and reparability (Taylor, 2014a). The method is about making it easier to perform maintenance, reducing downtime and avoiding injuries when repairing. A common way to measure maintainability is from Time to Repair (TtR), a factor obviously desired to be as low as possible. This can be applied to a product as a whole or on separate parts if it is a larger assembly of components (Taylor, 2014a). There are two kinds of activities that can be examined for any product, preventive maintenance and remedial maintenance. Preventive maintenance is about performing service of a product before it breaks down. It can be about replacing certain old components with new ones, although they might be fully functional since earlier experience has shown the specific components to be prone to break after a certain time of service. It could, for example, mean changing the oil filter in a car before the filter fails and possibly causes great damage to the engine.

The remedial maintenance is what is done after a product fails, in other words, repair. This can be seen as more expensive than preventive maintenance, especially if it applies to a large quantity of a product. For example, bearings in a machine. Having it standing still for unplanned maintenance many times over to change failed bearings one by one will be more expensive than changing all the bearings at once as soon as one goes out - of course, the most viable solution would be to plan to change them all before any of them breaks down.

One important part when designing for maintainability is to have the knowledge to estimate early on the reliability of components and how prone different parts are to require maintenance. In Figure 13 shown below is the so-called Bathtub Curve that illustrates the general reliability of products. The beginning and end of a products life-cycle are where it is most prone to failure. Some products are designed as “throwaways”, to not receive any maintenance at all during its lifespan, while other products are designed to be serviced somehow, and lastly there are products that are made for maintenance, repair and rebuild (Taylor, 2014b). They all generally follow this curve nonetheless.

![The Bathtub Curve, as described by Taylor (2014b)]
A ballpoint pen is an excellent example of how a product can be designed to either be a “throwaway” or something that lasts. It can be designed to last as long as there is ink in it, but after that time of use, it loses its function, have reached the planned lifetime and cannot be refilled in any way. Another way to design the pen is to make it possible to refill and durable in the overall construction. And lastly, the pen can be designed so that it is possible to refill and to change parts when they are worn out and with great care, it can last forever (Taylor, 2014b)

When discussing repair, the definition “lines of maintenance” often are included. There are three lines of maintenance. The first line of maintenance is service conducted where the product is used, like for example changing the oil in your car in your garage. The second line of maintenance is performed at a service point of some kind not placed too far off from where the product is being used. The second line is usually utilized when special skills or tools are needed when for example changing the brake pads on your car. The third and last line of maintenance is at the manufacturer. Something with the product is usually causing severe errors if this is needed. This seldom happens within the car industry with it being such a well-established market with long developed service points. This is more common if the manufacturer is new to the market and service points have not been established yet. One way to facilitate first line maintenance is through modularity. The subassembly at fault can be swapped out for a new one and then be sent to the second or third line of maintenance (Taylor, 2014a).

Design for maintainability can benefit greatly from DFD which allows for easy access to components when they are in need of maintenance or repair. Design for maintainability is about following some rules, with a couple of them being straight up obvious to many. The first rule of all is that the design for maintainability is created during the design stage and not after (Taylor, 2014a). The designer needs to consider where the maintenance will take place, if it is in the first, second or third line. Try to keep the design simple, complex parts are usually more difficult to maintain. If parts cannot be easily accessed for maintenance, they should be designed with as high reliability as possible.
4.6.5 Design for Remanufacturing

Design for remanufacturing, DFRem, is about product recovery (Sundin & Bras, 2005). It is in a way about both DFA and DFD combined. It is about ease of assembly, ease of disassembly and ease of reassembly – in other words, remanufacturing, see Figure 14 below. Only about 15% of a product that is taken back from customers today are somehow recycled or remanufactured while the rest is thrown away and seen as waste (Das & Naik, 2002).

![Figure 14. The generic steps of remanufacturing (Sundin, 2002).](image)

Design for remanufacturing comes with many benefits and possible earnings. It is seen as the ultimate form of recycling (Steinhilper, 1998). The reuse of one or more components in a product does not only reduce material resources used, which traditional recycling also would fulfill, but also reduces the need for material forming processes. This is great out of an environmental and sustainable perspective – with manufacturing process often being time and energy consuming – but also beneficial from an economic perspective (Hammond, et al., 1998).

A way to be successful with remanufacturing is through providing the customer with a hybrid offering. Products that are sold through functional sales are often easier to control, monitor and gather usage data from (Sundin & Bras, 2005). With greater control over the products, it is easier to get the products back. With information from how the products have been used, it can simplify the remanufacturing process with supplying knowledge of which part that has been worn out and must be replaced. Information about which components that are more prone to get worn out also help to improve the product design regarding future remanufacturing and durability.

In order to determine if remanufacturing can be profitable, there are a few criteria that need to be met according to Lund (1984). The criteria are divided into screenings, with each screening passed indicating an increased viability for remanufacturing. The screenings are not infallible and a pass through each one of them does not guarantee that remanufacturing will be profitable (Lund, 1984).
Screening 1

1. The product is a durable end product.
2. The product typically fails functionally rather than through dissolution.
3. The product must have a core, a high-value component.
4. The remanufacturing process can restore the product to its original shape and function.

Screening 2

1. The product is repairable.
2. The products are factory-built as opposed to field-assembled
3. The product is standardized and made with interchangeable parts.
4. The cost of obtaining the core is not of significant value compared to the value of the remanufactured component.
5. The remanufactured product is valued and/or sold at a high percentage of the original products price.

Screening 3

1. The product is not currently being remanufactured.
2. There is a high ratio between the value of the product and the assembly labor costs.

Screening 4

1. The technology in the area is not rapidly evolving and/or the product is not affected by it.
2. Product transportation back and forth must be lower than the value gained from remanufacturing.
3. There is a low ratio of undifferentiated material to the total amount of material in the product.
4. The product is serviced or installed by an organized service agency network.
5. There is a high ratio of the current product population value to the average life of the product.

Furthermore, Lund (1984) explains that a feasibility score questionnaire should be conducted as another way of determining if remanufacturing could be profitable. Feasibility score is based on seven questions about the product and its lifetime and results in a score. This score will then indicate if the product should be remanufactured or not.
Uncertainties and complications that can follow the implementation of remanufacturing cannot be left without consideration (Sundin & Dunbäck, 2013). It is a difficult problem to solve seen from a logistic standpoint with take back of product and core availability being some of the impacting factors. The understanding and function of the supply chain, especially the reversed one, is crucial to develop early, see Figure 15 (Sundin & Dunbäck, 2013). The timing of demand and supply is a challenge with an example of more products coming in from customers than are being shipped out, resulting in an overflowing inventory - or the other way around (Guide, 2000). Forecasting the condition of cores that come back from customers in order to more effectively plan the remanufacturing of new products is also a huge challenge. Another risk of investing in remanufacturing possibilities can be technical development leading to products becoming obsolete which results in cores being useless.

Figure 15 - Forward and Reverse Supply Chain (Sundin & Dunbäck, 2013)
Theoretical Framework
4.7 Analytical Model of Theoretical Framework

From the theoretical framework presented so far, we can form a holistic analytical model for interpreting the constituent parts of the theory in a more stitched-up together version. The analytical model for is shown in Figure 16. The model builds on the key factor of developing a PSS — to use a life-cycle perspective (Sundin, 2009). DFX tools is a designer’s way of improving a specific phase in the life-cycle of a PSS. The PSS perspective helps when it comes to understanding which parts of the life-cycle a specific manufacturer should mostly focus on and what incentive there is for pursuing e.g. remanufacturing. But questions as, which resources and capabilities should be leveraged to build a PSS? What is the formulated service growth strategy behind all this? These are questions more deeply covered in the research on IPSO (e.g. Kowalkowski & Ulaga, 2017). While that research focuses on business logic behind these concepts, the business logic research of services does not give specific tools on how to develop products-service systems to fit that logic.

This gap between design research of DFX and Product Service Systems — and the business research of industrial service development — can shrink by applying the concepts of service growth strategies (the research from industrial service development) with that of PSS and how to design products with a life-cycle perspective. The merging concepts are holistically shown in Figure 16 and form the analytical research model of this study. In other words, a service-growth and a PSS perspective merged to one.

With the service strategy and business logic in place — the design for Product Service System takes place with a life-cycle perspective (see Figure 16). Based on Sundin (2009), the life-cycle phases start from raw material, part manufacture, product assembly, delivery, usage, takeback maintenance and re-manufacturing of either whole product, specific parts or raw material (see Figure 16). The life-cycle provides a good framework for understanding which DFX tool is needed from our designer’s toolbox at a specific phase. To reach the service growth strategy target position, value-added services can also continually be added through several PSS life-cycles, especially in the usage phase, these can be services as presented by Kowalkowski & Ulaga (2017) — Product lifecycle Services, Asset Efficiency Services and Process Support Services (see Figure 16).
Theoretical Framework

Figure 16. Thesis framework for analyzing a manufacturers service growth strategy and how to design for product/service systems through a Life-cycle perspective with DFX methods from the "designer’s toolbox".
Theoretical Framework
5 Results from interviews

In this chapter, the results from the interviews are presented. Respondents represent different roles from production, sales/marketing, aftermarket, R&D and the CEO at Strömsholmen. Table 2 shows which departments the respondent’s works at.

Table 2. Respondents respective working division at Strömsholmen.

<table>
<thead>
<tr>
<th>Division</th>
<th>Number of people</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production support</td>
<td>1</td>
</tr>
<tr>
<td>Aftermarket</td>
<td>1</td>
</tr>
<tr>
<td>CEO, Sales/Marketing</td>
<td>5</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>4</td>
</tr>
</tbody>
</table>

The overall response from the interviews indicates a variety of views which generally reflects the department and position the respondent represents at the company. Meaning, a variety of challenges is brought forth by the respondents with an equal variety of solutions to those challenges. The results from these responses are presented in the following chapter, challenges at Strömsholmen and aftermarket and service growth.

5.1 Challenges at Strömsholmen

When asked about the challenges faced by Strömsholmen today, a variety of answers arose. One respondent from Sales/marketing explained it this way:

“Within Tool & Die, we are market leader and thereby always chased. It is a challenge to keep our position and serve our customers in a satisfying way, so they’ll return. Within suspension we are new-comers and there it is all about growing and taking new positions...

...The challenge within all segments, is that we sell hardware and that will not be enough in the future. We have to bundle different services to it.” – Sales/Marketing respondent (2018-03-21)

The respondent goes on to explain the importance of bundling these services in a way that it can be delivered so that Strömsholmen makes a profit. Because it is another matter creating services that the distributors can deliver. The respondent summarizes the point by explaining that it is hard to do something we have not done before:

“Make a hard item that looks stable and then sell it with a markup. That kind of thinking sits in the walls here.”

– Sales/Marketing respondent (2018-03-21)

The CEO also explained that one of the main challenges short term is:
“...the continuing price pressure in Tool & Die and to maintain the market leading position with brands for a continuing price premium in the market.” – CEO (2018-03-23)

When asked about possibilities to move towards a process approach for Strömsholmens Tool & Die customers with an offering of uptime or similar the CEO responded that:

“Yes, it has been discussed. We have some projects that are moving there. I guess the technology is developed. I don’t think that the end customers are mature enough for it though. Not mature for the payment model. They have talked about pay per stroke for gas springs for 10-15 years. But the end user need systems so that they can handle it. They probably think it is too much of a hassle. For pressing tools, the gas spring only constitutes around 5 percent of total costs.” – CEO (2018-03-23)

Specifically, on service for Hydrop suspension, the CEO explained that:

“We need to go back and take a new approach. Because as a company we are probably thinking a bit wrong about delivering back Hydrops in new condition. Then it will be too expensive, and no customer wants to pay for it. Or, if we need to do it as a warranty repair it will become too expensive for us and therefore the whole business falls out.” – CEO (2018-03-23)

Another respondent explained that Hydrop and other suspension parts would be better off produced in-house:

“Components that everybody can manufacture should be brought in. The things that are more difficult and uncommon should be made by us. Right now, it is the other way around.”
– R&D respondent (2018-03-22)

More than one respondent explained that it is a pity that the suspension parts are not made in-house today but that it is good that at-least the assembly is done in-house:

“It is unfortunate that the disassembly site was put together so quickly without a proper vision of how it should be. However, it is good to have some place to start with the disassembly work.”
– Production support respondent (2018-03-21)

The respondent further expressed that it is good they have opened up the question of reuse of components, adding that:

“It would have been interesting to see if one could reuse the piston rod of the suspension. Could one remove the chrome layer and add new chrome finish? I could imagine that it is not much wrong with the steel itself, just that the surface is torn. It would have been interesting to hear more about this. To work with reusability.” – Production support respondent (2018-03-21)
Another respondent was asked about putting themselves in the customer's shoes when it comes to the suspension products and what they then would want from Strömsholmen in that situation:

_If I would call Strömsholmen and buy a product, then I would like to get an answer to, if we would drive our vehicle in a certain way, what product do you think is best suited and why? Is it an inline or a piggyback (two different suspension configurations)?_  
_Do I need a height control system, why? How long does the product hold up and how do service work? You would like to be able to ask these questions and get a good picture of how it works._  
_You would like straight answers to these questions._  

— R&D respondent (2018-03-20)

Another respondent expressed a view of why, during the disassembly of some Hydrop, the threads were breaking off:

_“I believe that many of the problems we are experiencing right now with the threads breaking off has to do with our equipment, both concerning assembly and disassembly.”_  

— R&D respondent (2018-03-22)

The respondent also explained this about service of Hydrop suspensions:

_“Service, if needed, should if possible be conducted on-site. The user doesn’t want to wait and be without suspension for a long time.”_  

— R&D respondent (2018-03-22)

A majority of the respondents mentions that one of the main issues with the development of Hydrop today is the silo mentality. Departments are not working close enough between each other and information gets lost. This is an obstacle that has been acknowledged, and they feel that it needs to be taken care of in order to both meet the requirements from customers but also to have a collective mindset towards how value is created and kept within the company.

_“We need to be better at working across different departments. That is something that we have been missing in earlier projects. This is something that needs to be implemented from the start.”_  

— R&D respondent (2018-03-22)

When Strömsholmen started developing H5, the R&D department found that constructing them was at such a low cost that service would be redundant and instead customers might as well buy a new one in case of failure.

_“Looking back, one mistake we made is that we didn’t think of serviceability from the start. Components tend to break during disassembly and parts that didn’t need service has to be switched out for new ones..._  
_...We are not giving away our services for free but we are not making any money on them either. We need to be more effective and not break stuff to be profitable.”_  

— CEO (2018-03-23)
One respondent expressed how to think differently within R&D:

“We need to think more like engineers and less like CAD-designers. Go back to the laws of physics to understand the concept of Hydrop. This would help with implementing modularity. Once we understand the basics we can build up from there. Tests wouldn’t be about seeing what will happen but rather to confirm a certain model.” – R&D respondent (2018-03-22)

In order to implement modularity and a way to increase the level of serviceability, the respondent explains that Strömsholmen needs to get back to the roots of Hydrop. They need to understand the physical connection between the nitrogen gas and the oil and how to make mathematical calculations and draw conclusions between the two of them.

“The main function of Hydrop is suspension and cushion. The rest is just support functions. Like containing the oil and gas” – R&D respondent (2018-03-22)

To adapt products more to production and serviceability a respondent explained that:

“It all comes down to collaboration and communication between the design engineers and the production staff. That needs to be developed from the start.” – CEO (2018-03-23)

On the topic of challenges at Strömsholmen, the respondents showed a variety of responses. The main challenges that occurred can be summarized into the following bullet points:

- Selling hardware with a markup is the common thinking at Strömsholmen. A product-centric mindset makes it harder to move more towards services.
- There is a continuing price pressure at Strömsholmen bulk segment, the Tool & Die segment, which makes it harder to keep a premium price level.
- An ongoing discussion of using a pay per stroke type of business model for Tool & Die has been discussed for a long time. However, the end user needs systems to handle it which they might not be ready for.
- Delivering Hydrops in a new condition after a service has proven to be a challenge for Strömsholmen. Either it is too expensive for the customer or too expensive for us in which case the business falls out.
- A challenge is handling service when most Hydrop parts are not made in-house.
- The disassembly area (for Hydrops) was put together too quickly without the proper vision of how it should be.
- A silo mentality within departments makes it harder for cross-functional work.
5.2 Aftermarket and Service Growth

On the topic of aftermarket and service growth on respondent expressed the potential in services and developing an aftermarket organization as seen in the response below:

“When a Tool & Die gas-spring is used up, you toss it away. While for Hydrop you send it back, for 30 years. What a great income opportunity for us...

... The Hydrop customer is stuck with us and therefore we should offer as much services as possible. If they are happy we can win the next project. The suspension products are relatively new, so when the first products come back for service is it somewhat of an awakening. Oh, service. How do we do that? That is why one employee have as an assignment to pinpoint the service process and give an organization proposal, so we can move it forward. What organization do we need to make something good out of this? Even though this is a small part of revenues is it at least a place to start and it is very concrete.”

– Sales/Marketing respondent (2018-03-21)

The respondent explains that many military vehicle manufacturers are almost as “bad” as Strömsholmen when it comes to service. In one case, a country only has a budget of 200 euro per vehicle for service. However, the respondent elaborates on that services for Strömsholmen’s customer could mean a variety of things besides traditional product life-cycle services:

“Vehicle manufacturers are very concerned about getting their projects. When they get a project, they need to hire a lot of people and then there is a period of less projects. They keep a small group of people with core competencies. But that core competence might not be enough to drive all work in the company. So, they have a need for help. Can we provide with that help? We could sell services. What type of services? It could be within training, producing material and instruction books. If we had connected products we could draw conclusions from data, etc. I think there is a ton we could develop here.”

– Sales/Marketing respondent (2018-03-21)

The respondent further explains that it is interesting to look for service solutions that are easily scalable:

“When the start-up costs might be higher but when you get the volume it creates a large effect”

– Sales/Marketing respondent (2018-03-21)

Some respondents where more skeptical of the potential of services, arguing from a customer’s perspective:

“I believe that the customers need for services are very limited at the moment.” – CEO (2018-03-23)

Another respondent expressed that there are possibilities of selling products and services online:
“If you consider roughly 10 years in the future. Who would want a salesperson that sells your products? That you can buy online. Then it is possible that we need to sell services, so the customer chooses us” – Sales/Marketing respondent (2018-03-21)

The respondent also considers challenges around services for the Tool & Die segment:

*It is easy to sell services to Volvo Cars from here. But we work globally, the world is big. We have customers everywhere. The question is how we can sell services and how to bundle it to be in all markets? Do we need our distributors onboard?*

– Sales/Marketing respondent (2018-03-21)

One respondent claimed that the take back of products for service could be made redundant if the Hydrops are treated correctly and, in some way, serviced on-site:

“I think that it would be neat if a distributor or equivalent had certain service equipment and tools for diagnostics. They could go out to the customer and check for faults and send them away for service only if needed. Essentially, in my opinion, the only service needed for a Hydrop is oil change and maybe some refill of nitrogen gas. If that is done regularly, a Hydrop should last for 30 years” – R&D respondent (2018-03-22)

A couple of other respondents explains that in order to perform a correct service the products should be sent back from the customer to Strömsholmen:

“Simple things like refilling the gas can be done on-site. And changing of a bearing or similar can most certainly be made without bringing it in. But service concerning the inside of the Hydrop, like oil change and seal replacement need to be done in a clean environment. All internal parts are super sensitive to dirt.”

– R&D respondent (2018-03-28)

Regardless of the differences expressed of what services can be, the CEO explains that:

“Services needs to be connected to the value it will create for the customer. We can’t develop something without having requests from customers. And of course, our cost for providing a service needs to be lower than what the customer is ready to pay.”

– CEO (2018-03-23)

During the 30-year lifetime Strömsholmen promise to provide the Hydrop suspension, also poses opportunities — as one respondent explained:

“What we looked at is if we sell one Hydrop we could sell the same Hydrop three-four additional times if you consider incomes from maintenance and services”

– Sales/Marketing respondent (2018-03-21)
One respondent from R&D explained that what’s important to them is to get back products and receive feedback on how they perform after say 4 years because the customer wants to feel secure in the product. The respondent explained that collect data that could be measured from the vehicle's suspension and logged would be of value to R&D:

*The road profile would be interesting to measure. Just how the products are used. Is it large piston strokes or many small ones? To later do measurements on how piston seals hold up under those conditions, let’s say 50 000 km. That would have been useful. Also, inner temperature would be interesting. They can get very hot. Is the surrounding environment hot or cold?... much of such data would be useful.* — R&D respondent (2018-03-22)

On the topic of Aftermarket and service growth at Strömsholmen, the main arguments that occurred can be summarized into the following bullet points:

- Since Hydrop is a product that shall meet the tough military standards of 30 years of function. This poses a great income opportunity for different services.
- The take-back of hydrops is somewhat of an awakening, which has led to assigning an employee to make a service process proposal as well as an after-market organization proposal. A concrete way to start.
- An argument for a different type of service Strömsholmen could offer is to provide vehicle manufacturers with consultant services in their projects which they are very keen on getting.
- Services that sold to vehicle manufacturers could include training, production material and instruction books.
- If Strömsholmen had connected products they could draw conclusions from data. Data like the road profile curve of each Hydrop. Some of the data could be value-adding to customers and also inform Strömsholmen of product usage like if the piston strokes are large or small? Which in turn informs R&D on how to improve the products.
- Temperature is another data of Hydrop that respondents explained could be of interest.
- Services that are easily scalable are of extra interest. But they need to be connected to the value it creates for the customer. The cost of providing a service needs to be lower than what the customer is ready to pay.
- Others believe the potential for services is very limited at the moment.
- Selling services online is likely in the future.
- Concerning Hydrop, an argument made is that the takeback of products could be made redundant if service checkups were made at the customer site. A “diagnostic” of the product could mean a basic nitrogen gas and oil change. If done regularly a single Hydrops should last for 30 years.
Results from interviews
6 Analysis of Interviews

This chapter contains the analysis of the eleven interviews in light of Strömsholmen’s background and the theoretical framework.

The results from interviewing eleven people from different departments at Strömsholmen showed a number of things that correlate with literature. Starting with the challenges at Strömsholmen one respondent said that; as a market leader in a segment, you are always chased. The CEO emphasized the continuing price pressure in their main market segment (Tool & Die). This is exactly what Kowalkowski and Ulaga (2017) argue is one of the main reasons manufacturers should pursue service growth. That is if markets become saturated and commoditized which makes it harder to differentiate. Another respondent recognized this and argued that to stay competitive, they need to bundle different services to their products.

The same respondent expressed the potential in growing their service business for customers. Voicing that Hydrop is a product that shall meet the tough military standards of 30 years of functionality. Therefore, they should figure out how to offer as many services as possible during that time. Products with a long life, Tukker & Tischer (2006) argues, is one condition when the PSS approach generally works well for manufacturers. Other conditions are products where operational failure or downtime is not tolerated. and products with only a few major customers on the market, similar to Strömsholmen.

Other respondents had a more product-centrally focused view of services. Closer to the second definition of services as defined by Grönroos (2013). That is services as an activity such as a repair or maintenance. Only one respondent expressed broader views of services with Grönroos (2013) first definition of services. Namely, services as a perspective on business. In other words, services that go beyond traditional product lifecycle services.

Some respondents expressed that the common thinking at Strömsholmen is to sell hardware with a markup. That a product-centric mindset sits within the walls of Strömsholmen. On the other hand, in Strömsholmen’s mission statement, it says, “To develop, produce, and sell products and services based on gas spring technology.....”. Kowalkowski & Ulaga (2017) states that a firm's mission statement is the definition of the purpose of the organization and the ambition of what it seeks to achieve to ensure its survival and long-term growth (Kowalkowski & Ulaga, 2017, p. 72). So, is service strategy aligned with corporate goals? Or not? Barnes Group seems to recognize that there is an increased focus to prolong service life on military vehicles, more focus on “function per dollar” and that they need to establish more contact with the military end user. But does Strömsholmen have the same point of view?

Based on the respondents’ image of Strömsholmen, where do they land on the product-service spectrum adopted by Kowalkowski & Ulaga (2017)? The answers point Strömsholmen to the left, where the relative importance of products well exceeds the relative importance of services. However, there seems from top management, an interest for a target position was the relative importance of services are greater than today. The question is how to get there? In choosing Grönroos (2015, p. 465) approach, the core of the offering has to be a value-creating support to customers, not a physical product or any other type of resource. If Grönroos approach is too extreme for Strömsholmen, a service infusion — gradually adding more
services to a product-centric offering, might be another way to go. This approach has the benefit of acting as a proof of concept before pursuing a more ambitious service strategy. Even Fang, et al. (2008) argue that initial service investment may not be profitable and that service growth beyond a certain threshold, generally around a critical mass of 20-30% of total firm sales is needed.

One respondent argues that services that are easily scalable are of extra interest. But they need to be connected to the value it creates for the customer. The cost of providing a service needs to be lower than what the customer is ready to pay. For building a service portfolio, Kowalkowski & Ulaga (2017) argues that growing from traditional Product Lifecycle Services (PLS) to Asset Efficiency Services (AES) is to shift focus from a cost-plus price setting logic to a value-based logic — That allows manufacturers to raise customers’ willingness to pay for AES.

One respondent explained that if Strömsholmen had connected products they could draw conclusions from data. Data like the road profile curve of each Hydrop. Some of the data could be value-adding to customers and also inform Strömsholmen of product usage, for example if the piston strokes are long or short, which in turn informs R&D on how to improve the products. However, several respondents mentioned that getting live data from a military vehicle would not be possible because of security issues. The collection has to be made afterward and retrieved from the vehicle while it is in service or in another way not being used. This goes in line with the reasoning from Ulaga and Reinartz (2011) which emphasize that the most strategic asset held by manufacturers today is installed base product usage and process data. But just acquiring this data is not enough according to Ulaga and Reinartz (2011). Manufacturers also need to build Service related data processing and interpretation capability. Developing skills to turn product use data into a source of revenue or new opportunities. Kowalkowski & Ulaga (2017) argues that to understand what data to collect the question must be asked of which key performance metrics truly matter to customers.

One respondent expressed that the takeback of Hydrops is somewhat of an awakening, which has led to assigning one employee to make a service process proposal as well as an after-market organization proposal for Strömsholmen. A concrete way to start. Concerning Hydrop, an argument made is that the takeback of products could be made redundant if service checkups were made at the customer site. A “diagnostic” of the product could mean a basic nitrogen gas and oil change. If done regularly a single Hydrops should last for 30 years without change. This could be turned in to a unique resource by Ulaga and Reinartz (2011) reasoning, if the aftermarket includes a field service organization.

The CEO of Strömsholmen summarized a major point that when developing Hydrop, “…we didn’t think of serviceability from the start. Components tend to break during disassembly and parts that didn’t need service has to be switched out for new ones…” It could be argued that the lack of designing with a life-cycle perspective in mind, which Sundin (2009) argues is key for reducing the need and cost of maintenance and repair, is the reason for this. Especially when designing for a product service system. This means that design must be considered both for physical products used in PSS and the services that are used during and between contract times (Sundin, et al., 2009).
7 Results from Workshop

The workshop conducted with four employees at Strömsholmen resulted in a number of service ideas for the suspension customer and users. The brainwriting session lasted 20 minutes and the discussion with using the PSS layer method lasted the remaining 40 minutes. In this time the discussion among the participants led to some new ideas on what they could offer and execute as a company.

7.1 Service Ideas

The workshop resulted in the following eight ideas based on the problem of “Services that can increase the customers expected value of Hydrop”:

1. Dialysis idea for Hydrop oil and gas exchange and diagnostic service.
2. An exchange program / rotational system for Hydrops since they degrade at different rates.
3. Measurements of temperature, stroke length etc. are logged and sent back to Strömsholmen.
4. Live feed for Hydrop from customer to Strömsholmen
5. RFID instead of QR-code to store driving performance/information that can be read.
6. Guidance and service through VR.
7. Online tools so customers understand how to adjust Hydrop on their own.
8. Instructions laser marked on piston rod or on cylinder tube.

The ideas were saved on notes where some of the ideas were further discussed in the group. One idea that was mostly discussed was the dialysis idea. The idea came out of a discussion of what is needed during a service of the Hydrop suspension. If Strömsholmen or a partner could perform an oil and gas exchange of the product on site instead of dissembling all of the product at home, in-house, much cost and time could be saved on both the customer and Strömsholmen part. Just like a dialysis on humans, an oil and gas exchange could provide valuable information on how well the product is holding up, by analyzing the amount of dirt and metal chips mixed in the oil and gas caused from product fatigue. The idea is to redesign the product with the first line maintenance in mind and provide a beneficial outcome-based service agreement for the customer.
7.2 PSS Layer Method

Following the service idea part, the participants were asked to come up with customer needs and customer values and write them on separate notes. After that, the participants discussed between each other the importance of every idea that came up, and which ones that were the most accurate and current. These ideas of customer needs and values were then placed in the PSS Layer Method. The needs are what the customer essentially wants to achieve with a Hydrop. The values are why the customer would decide to buy a Hydrop. The deliverables are what Strömsholmen needs to fulfill in order to satisfy the needs and values of the customers. The result of this exercise is shown in Figure 17.
8 Results for Hydrop H5

Based on the results from the interviews, observations, the workshop conducted and the implementation of DFX methodologies, this chapter contains the author's case solution for the gas hydraulic suspension system for Hydrop H5. The results of the study on Hydrop H5 is presented in the following order:

1. Observations of the disassembly of eight unused Hydrop H5.
2. Results from DFA, DFD, DFS, and DFRem-analysis.
3. Hydrop H5 as part of a Product Service System.

8.1 Observations of the Disassembly of Eight Unused Hydrop H5

In February 2018, a demo disassembly was performed on eight Hydrop H5 gas hydraulic suspension systems. This is the result of these observations and meetings.

All eight Hydrops had just been assembled a few weeks earlier, passed through some controlled tests in the factory and lastly dissembled. All eight Hydrops where able to be disassembled despite very high tensioned threads with a torque of 1400 Nm. However, 3/8 did not pass the test for being good enough for customer delivery. One reason for this is that the threads of several components (cylinder and gable) were partly damaged. One explanation for this that came up was that during the production of certain components, sandblasting left sand between the threads.

It was also discussed that Strömsholmen lacks a controlled process for disassembly of soft parts on the Hydrop products. Which today can scratch the steel surfaces of critical components.

With disassembly of Hydrop wear of the finish occurs at the top and the bottom of the product. Resulting in a discussion of repainting the parts. The decision on what to do after the demo could lead to the unwilling takeback of 552 Hydrops already in use by customers. This was considered undesirable since the product life test of Hydrop H5 is planned to be ~ 20 000 km and in that time the suspension will have expanded fully ~ 100 000 times.

The team responsible for the demo presented some learnings

- Ease of disassembly must be apparent in the product development process.
- The product must be prepared for aftermarket in the product development process (service kit, manuals, processes, standards, etc.)
- Strömsholmen should do a smaller project to investigate the threads and how to ensure they do not break.

The demo shows that material costs for discarded parts would exceed way above normal service costs for details, disassembly and assembly time. That is if other Hydrops follows the same patterns as the demo.
8.2 Results from DFA

To determine the theoretical minimum part count for Hydrop H5 — each part is assessed by Boothroyd, Dewhurst & Knight (2011) three criteria repeated here from the theoretical framework:

1. During the operation of the product, does the part move relative to all other parts already assembled. Only gross motion should be considered—small motions that can be accommodated by integral elastic elements, for example, are not sufficient for a positive answer.

2. Must the part be of a different material or be isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable.

3. Must the part be separated from all other parts already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible?

Application of these criteria to the original design (Figure 18) during assembly would proceed as follows, for each subassembly:

Figure 18. Hydrop H5 assembly view.
“Subassembly A” containing 14 parts.

1. “A-1” : This part could theoretically be combined with “B” since it does not disrupt the assembly of other components in the existing design. Therefore, theoretically not necessary.
2. “A-2” : The above statement would render this part theoretically not necessary, with its sealing properties not needed if “B” and “A-1” is combined.
3. “A-3” : Is today combined with “A-1” through welding. This could be done earlier, in the manufacturing process, by milling and lathing them out of the same workpiece.
4. “A-4” : The bearing is a standard subassembly of parts that are purchased from a supplier.
5. “A-5” (2) : Does not meet the criteria because of the assembly of “A-4”. However, one of the components could theoretically be removed if all the other components are inserted from one direction. Then it could be combined with “A-3”.
6. “A-6” (2) : If one of “A-5” is combined with “A-3”, one “A-6” can be removed. One of them is therefore theoretically not necessary.
7. “A-7” (2) : Necessary because of different material properties.

Resulting in a theoretical minimum part count of 8 parts.

“Subassembly C” containing 67 parts.

1. “C-1” : Since this is the first part to be assembled in this subassembly, there are no parts with which it can be combined, and so this is a theoretically necessary part. Also, the part must be separated from “D” because other parts like “C-5” would otherwise be nearly impossible to assemble or disassemble.
2. “C-2” (5) : These do not satisfy the criteria since they could be combined with “C-1”.
3. “C-3” : These do not satisfy the criteria since they could be combined with “C-1”.
4. “C-4” (15) : These do not satisfy the criteria since they could be combined with “C-1”.
5. “C-5” (33) : Since these moves relative to other parts, they cannot be removed completely. They could, however, be reduced in number at the cost of lower possibilities for customization.
6. “C-6” (5) : These do not satisfy the criteria since they could be combined with “C-7”.
7. “C-7” (6) : Must be separate for reasons of the assembly of necessary “C-5”.
8. “C-8” : Must be separate for reasons of material properties.

Resulting in a theoretical minimum part count of 21 parts.
“Subassembly E” containing 7 parts.

1. “E-1”: Since this is the first part to be assembled in this subassembly, there are no parts with which it can be combined, and so this is a theoretically necessary part.
2. “E-2”: Necessary part because of differences in material properties.
3. “E-3”: Criteria do not apply because it is a standard subassembly of parts, purchased from a supplier. Necessary also because of differences in material properties.
4. “E-4”: Necessary because of material properties. Improves guiding of “Subassembly E”.

Resulting in a theoretical minimum part count of 7 parts.

“Subassembly G” containing 8 parts.

1. “G-1”: Since this is the first part to be assembled in this subassembly, there are no parts with which it can be combined, and so this is a theoretically necessary part.
2. “G-2”: Must be separate for reasons of material properties. Necessary to seal oil in “B”.
3. “G-3”: Necessary because of differences in material properties.
4. “G-4”: Necessary because of material properties. Improve guiding of “D”.
5. “G-5”: Necessary because of differences in material properties.
6. “G-6”: Necessary because of material properties.

Resulting in a theoretical minimum part count of 8 parts.

“Subassembly H” containing 13 parts.

1. “H-1”: Since this is the first part to be assembled in this subassembly, there are no parts with which it can be combined, and so this is a theoretically necessary part.
2. “H-2”: Could be combined with “H-1” and therefore theoretically not necessary.
3. “H-3” (2): If “H-2” is combined with “H-1”, this part will theoretically not be necessary.
4. “H-4”: Made out of different material for its properties. Theoretically a necessary part.
5. “H-5”: Could be combined with the chassis of the vehicle but that is in the control of the manufacturer. Therefore, it is considered to be a theoretically necessary part.
6. “H-6”: Must be separate for reasons of material properties.
7. “H-7”: Could be integrated with the chassis of the vehicle but that is in the control of the manufacturer. Therefore, it is considered to be a theoretically necessary part.
8. “H-8”: Made out of different material for its properties. Theoretically a necessary part.
9. “H-9” (2): The bearing is a standard subassembly of parts that are purchased from a supplier.
10. “H-10”: This part needs to be separate from other parts because otherwise assembly of other products would be impossible. Thus, the part is theoretically necessary.
11. “H-11”: Could be combined with “H-10” and is theoretically not necessary.

Resulting in a theoretical minimum part count of 10 parts.
“Subassembly I” containing 5 parts.

1. “I-1”: You could consider combining this with the “Subassembly H”. However, in the original design, this part covers “Subassembly G” and would hinder the assembly of that part which is not possible with the original design, making it not meeting the criteria. Making the part theoretically necessary.

2. “I-2”: Could be combined with “I-1” and therefore theoretically not necessary.

3. “I-3”: This part generates tension between “I-2” and “I-4” which could be replaced by e.g. integrated snap fits and therefore is theoretically not necessary.

4. “I-4”: Could be combined with “I-1” and therefore theoretically not necessary.

5. “I-5”: Could be combined with “I-1” and therefore theoretically not necessary.

Resulting in a theoretical minimum part count of 2 parts.
Table 3. Summary of DFA Analysis.

<table>
<thead>
<tr>
<th>Part/subassembly</th>
<th>Number of parts</th>
<th>Theoretical minimum number of parts</th>
<th>Reduced by</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>14</td>
<td>8</td>
<td>43%</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td>C</td>
<td>67</td>
<td>21</td>
<td>69%</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>2</td>
<td>0%</td>
</tr>
<tr>
<td>E</td>
<td>7</td>
<td>7</td>
<td>0%</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>G</td>
<td>8</td>
<td>8</td>
<td>0%</td>
</tr>
<tr>
<td>H</td>
<td>13</td>
<td>10</td>
<td>23%</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
<td>2</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>118</strong></td>
<td><strong>59</strong></td>
<td><strong>50%</strong></td>
</tr>
</tbody>
</table>

Determining the theoretical minimum part count gives indications on part count efficiency but is not to be seen as an optimal part count. If the number of parts cannot be reduced by more than 40%, the original design can be seen as successful. It would indicate that none or very few parts could be removed from the original design without affecting its functions. 50% is however quite close and removing parts from Hydrop’s original design cannot be done without careful consideration. The percentage could have been lower if it was not for “Subassembly C” which with its high level of modularity and customization renders in a great number of separate components. Removing some of them would not affect the function per say but could certainly affect customization possibilities.
8.3 Results from DFD

Design for disassembly, in this case, renders in guidelines how to think when designing products for disassembly and reassembly rather than giving scores or indications on existing products.

Hydrop today is designed to be easy to assemble and to withstand tough environments without compromising the performance. Ease of assembling can in many cases also increase the ease of disassembly. However, it can also lead to difficulties and obstruct disassembly.

One example when DFA is disadvantageous towards DFD, which is the case with Hydrop, is if you choose to make a cylinder with threads on both ends. Tightening components to both ends simultaneously during assembly is easy and you can do it in one operation. However, when it is time for disassembly, components on one side of the cylinder is doomed to loosen before the other side gives in, making removal of the second side a lot more difficult.

With threads acting as a connector of multiple components, Hydrop is assembled in such manner that excessive force is needed in disassembly, resulting in many parts getting torn or scratched in the process. These problems also occur due to the lack of the correct tools, which is essential for a successful disassembly sequence. Accessing the core and making it free from all other components, regardless of damages made to other components, is therefore in some cases impossible.

Why DFD would benefit Strömsholmen can be summarized into the following bullet points.

- Instead of designing so that surfaces are easy to grip during assembly, Hydrop should be designed to accommodate good grip by adding pin holes or similar to avoid damaging the treatment of the surface.
- Following the statement above, Hydrop is in need of correct tools that facilitate disassembly and does not tear on the components.
- Design the components without compromising DFD for DFA or vice versa.
- Disassembly of Hydrops will give Strömsholmen invaluable information about its use, where it is worn-out first and after how long time it occurs.
8.4 Results from DFS

Design for serviceability applied on Hydrop was about evaluating time to repair, remedial or predictive maintenance and look into the different lines of maintenance, all to make Hydrop more accommodated for service.

Hydrops today are serviced with remedial maintenance, namely repair, although Strömsholmen wants to work with so-called predictive maintenance. The reason that remedial maintenance is performed is mainly because Hydrop is a newly developed product. As explained with the bathtub curve, there is a lot of “baby sickness” with new products, which requires repair. These early faults are difficult to predict and to avoid.

Time to repair is something that is of major importance for Strömsholmen's customers. A vehicle without fully functional Hydrops is obviously a disaster and useless. Time to repair can depend on different factors, one of them being DFD. If a part is easy to disassemble, it is easier to service and therefore can be performed faster. If the disassembly process is improved, so would time to repair.

Through the workshop, ideas on means on how to make Hydrop more fit for service emerged. One way, seen as preventive maintenance, can be to rotate the Hydrops from tire to tire. The eight tires that usually are the amount mounted on a vehicle does not receive the same stress and the Hydrops does not degrade in the same pace, with the front and back pair of tires absorbing most of the energy when the vehicle is in use. The rotation could lead to a prolonged lifetime of the Hydrops, resulting in a similar degree of exertion on all eight Hydrops and extended intervals between services.

Another idea of how to keep Hydrop available for the users is to perform something similar to dialysis on the Hydrops while they are still mounted in the vehicle. After a time in use, gas and oil have a chance of leaking into each other’s compartments, affecting the performance in a negative way. If a dialysis were able to be performed, it would be easy to examine if this was the case, and if so, separate the oil from the gas and refill the defected ones. This would be considered as a predictive, first line, maintenance.

Another idea, also within preventive maintenance, can, for example, be through implementing sensor into the Hydrops. They can give information about how they are being used and give indications on the probability of a product failing. Hydrops seen failing would if possible be serviced in the first line of maintenance, perhaps through a dialysis as described above. Although, if necessary, they would have to be sent back to Strömsholmen for third line maintenance. Here is where DFD comes into play and is crucial for the service to be profitable and time effective.

Once again, a short time to repair is, if a would product fail, of utter importance for the user. To utilize for first line maintenance, that also can be done predictively so that none of the products fail while in use, is therefore highly valued.
8.5 Results from DFRem

As a method to help determine if Hydrop can be profitable within remanufacturing, the screening method for DFRem presented by Lund (1984) was applied as evaluation.

Confirmed

Not confirmed or unknown

Screening 1

1. The product is a durable end product.
2. The product typically fails functionally rather than through dissolution.
3. The product must have a core, a high-value component.
4. The remanufacturing process can restore the product to its original shape and function.

Screening 2

5. The product is repairable.
6. The products are factory-built as opposed to field-assembled.
7. The product is standardized and made with interchangeable parts.
8. The cost of obtaining the core is not of significant value compared to the value of the remanufactured component.
9. The remanufactured product is valued and/or sold at a high percentage of the original products price.

Screening 3

10. The product is not currently being remanufactured.
11. There is a high ratio between the value of the product and the assembly labor costs.

Screening 4

12. The technology in the area is not rapidly evolving and/or the product is not affected by it.
13. Product transportation back and forth must be lower than the value gained from remanufacturing.
14. There is a low ratio of undifferentiated material to the total amount of material in the product.
15. The product is serviced or installed by an organized service agency network.
16. There is a high ratio of the current product population value to the average life of the product.

As can be seen in the figure above, Hydrops checks almost every item in the screening. The items that are grey are the ones that could not be confirmed, was unknown or was only partly fulfilled.

Other than that, a so-called feasibility score can make it possible to roughly determine whether a product is fit for remanufacturing or not, see Fel! Hittar inte
Results for Hydrop H5

Referenskälla. With Hydrops long lifetime and with a small chance for the technology to go obsolesce during this time, Hydrop is under great conditions for remanufacturing, according to Lund (1984). The score from the feasibility score ranges from 9,5 to -12,5. A score between 7,5 and -4 indicates that a product is suitable for remanufacturing. Hydrop got a score of -1,5. The following criteria are the ones that stood out and really showed that Hydrop is suitable for remanufacturing.

- 30 years or more before the technology will obsolesce.
- 30 years or more in an ideal lifetime.
- Service and/or installation is primarily made by Strömsholmen.
- The total cost for replacement of products on the market does not exceed $200 million.

From the above screening and the feasibility score, it is clear that Hydrop is next to perfect fit for remanufacturing. But fit is not the same as being ready. Some changes need to be made, above all within disassembly. As of today, many of the components need to be replaced in the remanufacturing phase because of wear and tear that occur during disassembly. This is not sustainable in the long run and in order to be profitable within remanufacturing, the reuse of as many components as possible without the need of processing them in any way afterward needs to be prioritized.
Results for Hydrop H5

8.6 Hydrop H5 as part of a Product Service System

To show how Hydrop H5 can fit as part of a Product Service System — this chapter contains the results of how that offering can work in practice and how to holistically see the Hydrop products as part of a product service system. The result is summarized in a business model canvas (BMC) as seen in Figure 19.

<table>
<thead>
<tr>
<th>Key partners</th>
<th>Key activities</th>
<th>Value proposition</th>
<th>Customer Relationship</th>
<th>Customer segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy vehicle manufacturers</td>
<td>Development, manufacturing, monitoring and maintenance of Hydrop suspension.</td>
<td>95% active suspension availability over 30 years.</td>
<td>Dedicated technical personnel</td>
<td>Military (Low budget)</td>
</tr>
<tr>
<td>Delivery service</td>
<td>IT-support partner</td>
<td>Cost-effective and robust suspension with custom dampening configuration.</td>
<td>“Fix it”- attitude</td>
<td>Military (high budget)</td>
</tr>
<tr>
<td>Hydrop Subcontractor s &amp; part suppliers</td>
<td>Key Resources Hydrop hardware and functionality data Technical skills</td>
<td>“The safer choice”</td>
<td>Military heavy vehicle manufacturers</td>
<td>Military heavy vehicle manufacturers</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channels</th>
<th>Revenue Streams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web-info</td>
<td>Initial product sale</td>
</tr>
<tr>
<td>Service competent sales force</td>
<td>Outcome based contracts — Active uptime service agreement</td>
</tr>
</tbody>
</table>

Figure 19. BMC over a PSS for Hydrop H5.

The business model presents a level of servitization where the relative importance of services has significantly increased, but where the offering is still — to some extent — product-centric.

**Value proposition.** In delivering Hydrop as part of a PSS, the nature of the value proposition would change from delivering the products with traditional product life-cycle services towards asset efficiency services. In practicality, this would mean that after initial product sales to the military vehicle manufacturer, Strömsholmen would make an outcome-based service contract with the military vehicle user. Instead of paying for specific service or maintenance when something goes wrong the user would pay only for the specific outcomes achieved (e.g. 95% availability). For the customer, this means lowering the risk of vehicle downtime. This helps to give the right incentive for Strömsholmen to pursue the cost reductions made possible with
DFX methods. That is because the customer pays for when the products work instead of when they are not. This shift in value proposition would still be in line with cost-effective and robust suspension with custom dampening configuration. A value proposition that takes Strömsholmen overall slogan of being — “The Safer Choice” — to the next step.

**Customer Segments.** The customer segments can be divided into the military (high vs low budget), military heavy vehicle manufacturers and possibly in the future even non-military heavy vehicle manufacturers.

**Channels.** To deliver the value proposition towards the different customer segments would happen much like today through web-info and a service competent sales force.

**Customer relationship.** To build and sustain the customer relationship dedicated technical personnel with a “Fix it”-attitude is needed to help the customer.

**Key activities.** The key activities would continue to be development and manufacturing but also to a higher degree monitoring and maintenance of Hydrop suspension.

**Key resources.** The key resources are Hydrop hardware and functionally data. To a large extent, the intangible resources as technical skills among employees are also a key resource for continuous improvement of the PSS.

**Key partners.** Heavy military vehicle manufacturers are not only customers but partners in the PSS. Other key partners are the delivery firms and Hydrop subcontractors and hardware/part suppliers. New with a PSS business model is that an IT-support partner to handle data could be needed.

**Cost structure.** Costs are split between development costs, service costs, product material costs, employee salary.

**Revenue streams.** The initial revenue for Hydrop as part of PSS can still be the initial product sale to the military vehicle manufactures. It can also be consulting work with a new vehicle project on how to design work with their suspension. It can also be training in how to use the products part of the PSS and how to optimize the vehicle performance. When it comes to the buyer of the vehicle an outcome-based contract can be signed that generates periodic income based on a specific metric instead of a specific service or maintenance. This metric could be a number of things measured e.g. 95% availability, the vehicle mileage, active suspension time or total number of expansions. Additional revenue can come throughout the 30-year lifetime of the Hydrop PSS system with additional product upgrades or additional services added along the way.
9 Discussion

This chapter contains the discussion of results presented and the methods used to receive those results.

9.1 Results Discussion

The quest to answer the thesis problem statements yielded a range of results. Ranging from interviews, workshop, observations, DFA/DFD/DFS/DFRem to analysis and a PSS business model.

Interviews. Interviews granted a deeper understanding of the challenges that the departments and the company as a whole are facing. Issues around performing service on Hydrop and how to deal with the aftermarket. How can we sell services bundled with products? What is the potential of offering services over the 30-year lifetime of Hydrop? The interviews shone light upon the problems that servicing a Hydrop could almost cost as much as making a new one from scratch. Giving headache to Strömsholmen engineers were some of them just wanted to scrap any Hydrop that failed. Or as the CEO stated: “…we didn’t think of serviceability from the start. Components tend to break during disassembly and parts that didn’t need service has to be switched out for new ones…”.

Workshops with employees of different departments at Strömsholmen. Results from the workshop led to nine different service ideas. The workshop gave ideas on how to perform first line maintenance and implementing sensors into the Hydrops. It also gave ideas on how to increase Hydrops lifetime and time between services, through rotation of Hydrops from tire to tire. A discussion of one of a “Dialysis” idea also arose. In that scenario Strömsholmen would perform an oil and gas exchange of the product on site instead of disassembling all of the product at home, in-house, arguing that cost and time could be saved on both the customer and Strömsholmen part. Just like a dialysis on humans, an oil and gas exchange could provide valuable information on how well the product is holding up, by analyzing the amount of dirt and metal chips mixed in the oil and gas caused from product fatigue.

To represent how this idea would work in practice and which need it satisfies, the participants were able to use the PSS layer method to map out the ideas. More importantly, the participants were pushed to think “service” when coming up with ideas and how PSS ideas could be represented in a visual manner, all done in a one-hour workshop.

Observations of disassembly. At the observations made of Hydrop being disassembled it became apparent that the challenges were many. Scratches on surfaces and threaded pieces stuck together, unable to separate, were some of the problems that occurred. Strömsholmen realized that the disassembly of Hydrop had to be improved greatly. The components were too valuable to dismiss.

Design for assembly. The DFA with its theoretical part count is not directly about changing the design of a product or a part, but rather to present new ways of thinking for designers and help them to be innovative. With that mentioned, the results from the DFA is not to inform redesign decisions strictly but to act as guidelines and ways to think in simpler product structures. The main objective with the DFA was to make Hydrop easier to handle with fewer parts, resulting in a faster and more accurate assembly process. Some of the changes might not even be fully viable in the sense of
Discussion

optimized performance. However, all the changes that would come from theoretically minimum part count were made to still maintain Hydrops functions and not in any way obstruct or impede on how they are manufactured today. One of the design changes would mean that all assembly would be unidirectional, something that is often considered to be superior to rotate or in other ways moving the product during the assembly. Strömsholmen have as their mantra to “Simplify, simplify, simplify” and this is most of the time something great. But when it comes to DFA, more, simpler parts compared to few complex parts often tend to be more expensive since they require more parts to handle during assembly and disassembly, which will be more time consuming, and imply a larger inventory of different components.

**Design for disassembly.** When talking about DFA for a product such as Hydrop only part of the job is done if DFD is not included. Only focusing on DFA is equal to saying that Hydrops should be scrapped if they were to fail. Hydrop with its high-value components should never be considered to be thrown out. That is nothing but an ignoble shortcut. However, it became apparent through discussing DFD what was the core of Hydrop and that design for disassembly, unlike design for assembly, doesn’t need to be applied on the whole product, only on the necessary parts connected to the core.

**Design for serviceability.** Through the connection between the workshop and the DFS theory, ideas of how to make Hydrop more fit for service emerged. The idea of performing dialysis on Hydrop while they are mounted on a vehicle is aligned with the serviceability philosophy that maintenance should be time and cost effective. The dialysis, if performed at the beginning of the use phase, could also lead to products avoiding early failure. As described in the bathtub curve, products are most prone to fail at the beginning and end of their lifetime (Taylor, 2014a). Similar to an oil change in a car, the first one is critical and should be conducted within the first 100 hours of use. This is because of small pieces of metal, that are almost impossible to remove during manufacturing, will come loose within the first period of use. The same applies to Hydrop.

The other idea of implementing some kind of sensor to Hydrops is also in line with the theory and gives the opportunity to perform predictive maintenance without really having to predict what is going to happen but rather read the sensors instead. This means that repair or replacements of components that are perfectly fine won’t occur, saving money and time.

The potential benefits of these ideas cannot be argued against, but it is questionable how feasible they really are. Since the ideas came from the workshop, which included a collective experience of over 45 years at Strömsholmen, one could argue that the ideas should be bulletproof. On the other hand, the participants of the workshop had instructions of brainwriting above and beyond their imagination, which could imply that the ideas could lack realizability.

**Design for remanufacturing.** It is not only through different tools of DFRem it becomes clear that Hydrop should be remanufactured. It is mainly consisting of large pieces of metal, that are expensive to manufacture with all the material that is needed, see Fel! Hittar inte referenskälla. The reuse of those components, for an as good as new product, would arguably be valuable to Strömsholmen.
Hydrop H5 as part of a Product Service System. The major difference from existing business model is offering an outcome-based service agreement to the military vehicle buyer. This could arguably create additional periodic revenue streams to Strömsholmen as they offer new services through the 30-year product lifetime. Instead of paying for specific service or maintenance when something goes wrong the user would only pay for the specific outcomes achieved or performance held (e.g. 95% availability). An important aspect is to make the customer susceptible to this type of offering by clearly explaining the benefits with a lower risk of downtime and critical failure.

The PSS business model presents a level of servitization where the relative importance of services has significantly increased, but where the offering is still — to some extent — product-centric. Taking the service infusion approach to growing a PSS offer. That is, extending the firms offering rather than moving away from product to service sales (Kowalkowski & Ulaga, 2017). However, Grönroos (2015) would oppose gradually adding services to a product-centric offer. Since he argues, the core of the offering has to be a value-creating support to customers, not a physical product or any other type of resource. We would argue, however, that making overly radical changes to Strömsholmen business models would result in larger resistance to those changes. Since Strömsholmen have a product-centric history, infusing services to grow their PSS business models can act as a proof of concept before pursuing more ambitious service offerings. Nevertheless, expecting instant increased profits might be a disappointment since if Fang, et al. (2008) is right, initial service investment may not at first be profitable and service growth beyond a certain threshold, generally around a critical mass of 20-30 % of total firm sales is needed.

The new business model helps to give the right incentive for Strömsholmen to pursue the cost reductions made possible with DFX methods. That is because the customer pays for when the products work instead of when they are not. How should this be achieved? We would argue, by designing for product service system with a life-cycle perspective. Adopting the products life-cycle phases and pursue value-adding services.
Lastly, the case of Hydrop H5 was used to make the results of this thesis as concrete as possible. Nevertheless, the objective of this thesis was to investigate how Strömsholmen could move towards more integrated product-service offerings and how to actually design their products to be easily assembled/disassembled, serviced and long-lasting. Consequently, are the results presented here generalizable across all Strömsholmen products? Even across different product portfolios? Even though the results are specific to Hydrop H5. We would argue that the methods used in this thesis are applicable across Strömsholmen other products, that in turn, could lead to redesign improvements and innovative PSS business models. Nevertheless, to fully prove this, future studies are needed.

9.2 Method Discussion

How can Strömsholmen move towards a more integrated product-service offering for Hydrop? To try and answer this first problem statement a broad range of methods and theories was used, yielding results that helped to reinforce each other and increase validity and reliability. Performing interviews, using workshop with brainwriting and the PSS Layer method as well as observing the test disassembly of Hydrop arguably not only helped to understand how Strömsholmen can grow their services business but also validate the feasibility of the results for Hydrop.

When holding semi-structured interviews, it is possible that the interviewer either steer to little or too much, which can affect how the respondent chooses to answer a question. A valid criticism, that we tried to counteract by carefully choosing questions. Core questions, that at first were more open and more closed as the interview progressed which Pharm (2014) argues is good to keep the interview focused on the desired line of action. Performing interviews with respondents from different departments also helped to gather a variety of views. However, no semi-structured interview was held with any of the assembly operating personnel which could have helped to further pick up issues from first-hand assembly experience.

When analyzing the interviews, a valid criticism is how to determine which parts of all interviews to analyze? By recording all interviews as well as transcribing each one, central themes could more easily be discovered, mitigating the risk of missing important responses.

To use a workshop as a method for generating ideas on new services proved to be useful, however using the PSS layer method with the participants in the workshop directly after the brainwriting was not optimal. If we would repeat the workshop we would have done this exercise on a separate occasion since much of the discussion from the brainwriting results dominated the workshop.

To present the final results of Hydrop as part of a PSS, a Business Model Canvas was used. In the BMC, the value proposition and how it is delivered to customers is an essential part. However, it could be argued that a BMC might not cover all nuances of a service offer compared to a sole product offering. On the other hand, a service as defined by Grönroos (2015) is to facilitate and support someone’s practices (process, activities; physical, mental) in a way that contributes to this person’s or organization’s value creation. Arguably, it should therefore be easier to make a BMC over a service than a product since this is directly connected to the value it delivers.

In trying to answer the second problem statement — Can Hydrop be redesigned to be more valuable to Strömsholmen and their customers? — the choice of designing
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Hydrop for a PSS with a life cycle perspective helped to understand the different phases of the product and how to design for each one using DFX methodologies.

In the choice between all possible umbrella terms of DFX methodologies, some were more seriously taken into consideration for this study than others. One reason that we chose the ones that we did was because they all in some way affected and complemented each other and together covered the whole lifecycle. Another reason was that the amount of information we were able to find about each DFX method could vary. E.g. DFA has an extensive history of research and have been broadly applied and verified within the industry, which makes the sources and information found more reliable and results can with more accuracy be predicted. DFA was also the method with the most obvious output with the theoretical minimum part count and the results that came with it. Using DFA step-by-step procedure forces designers to justify all of the parts and to consider alternative design otherwise not thought of. One pitfall when using DFA can be sub-optimization of a product, that on paper can look good but rather make things worse in practice. Another problem with DFA is that you use an existing design and can easily be locked in by that mindset, and the risk of missing out on the actual optimal design is rather high.

One could also argue that why use DFA when I can use design rules instead? But there is a danger in using design rules Boothroyd et al. (2011) would argue. Generally, rules attempt to force the designer to think of simpler-shaped parts that are easier to manufacture. But this can lead to a more complicated product structure resulting in a higher total product cost. The use of DFA and the rules for calculate theoretical minimum part count should yield the same result regardless of who may perform the analysis. However, there are subjective considerations to take when using DFA and any of the other DFX methods for that matter. This renders the repeatability of the results harder when using these methods. A valid criticism to consider whenever applying any of these methods. The main objective of determining minimum part count is however not to detect as many parts as possible to remove from an assembly, because this will hardly ever be the best design. It is more about forcing the designers to rethink and question design solutions that for them is seen as obvious or necessary.

To further counteract the inherent subjective considerations needed to be made when using the DFX methodologies, we verified results with the designers responsible for Hydrop at Strömsholmen.

A valid criticism is that in this study, a complete design for manufacturing analysis was not performed on the original Hydrop design. It is possible according to Boothroyd et al. (2011) to make cost estimations on machined components if you know — material cost, machine loading and unloading, handling between machines, machining costs, tool replacement costs and other machine data. However, in early design stages, this information might not be available. Surprisingly, it is possible to make approximate cost estimations based on component size. Simply put, for average to large sized workpieces the machining cost is mostly determined by the cost of the original workpiece. But the cost per unit volume increases rapidly for small components. Since nonproductive times do not reduce in proportion to the smaller component size. The surface area per unit volume to be finish machined is higher for smaller components. In the course of this thesis, this was delimited. Since the most expensive produced parts of Hydrop is “D” and that is because of its highly specified surface treatment and small tolerances, we saw little use by sub-optimizing the
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machining procedure of the Hydrop components, and instead simply use the design for machining guidelines and focus more on other phases of the life-cycle.

DFD, DFS and DFRem can be considered to be more of mindsets rather than methods that directly can be applied to an existing product. It is therefore vaguer what is really earned by using them. That can be seen as negative since it can be difficult to validate the value or determine the outcome before implementation. However, they effectively provide tools to guide the development of products and concepts, helping the designer to make the right decisions in these areas.

It can be considered that DFD was not carried out completely, with the absence of determining the most feasible route to retrieve the core of Hydrop. However, this was not prioritized, and might not even been possible to execute, since it required a lot of hands on of the actual disassembly process – something that was a rare sight during the period of this thesis. To carry out a complete DFD would require one person working daily with assembly of Hydrop, one designers involved in Hydrop and an actual Hydrop to validate the different choices.

A critical aspect to consider when using the DFX methods is that all methods under the umbrella terms have an equal amount of research and merit to it. Historically most DFX approaches are focused in on the early stages of the PSS lifecycle and that considering the usage phase more in early PSS design phases could potentially lead to design improvements that directly affect the user experience. Design for Product Service Supportability, DfPSS, is a method that was initially considered but later not used in the method with the main reason being that this method is scarcely written on. That which do is written on the subject focuses mainly on the importance of using DFX approach when designing for PSS. Which was already extensively covered in this thesis.

9.2.1 Ethical Aspects

When designing new products there is always an ethical aspect of how and who will use your products. Considering that the customers of Hydrop are heavy military vehicle manufactures and the users of these vehicles are countries in a military setting, you could ask what the ethical implications are for improving that product? One should be aware of the use of the products you design. It is clear that if the right suspension function is not delivered it can be a matter of life and death for the people in the vehicle.

In military settings there is often sensitive information, taking the right considerations and checking with Strömsholmen what information can be published is to take responsibility as an engineering student. To make interviews without providing a clear intention of its use can be considered unethical and therefore the respondents in this study were always briefed beforehand on the objective of the thesis and asked if recording the interview was okay.
10 Conclusions

Going from a product-centric to a service-based business models is a transition many firms set out to navigate. So how can Strömsholmen move towards integrated product service offerings for their gas hydraulic suspension — Hydrop? They need to adjust to a service business model with outcome-based contracting, so that a military vehicle buyer, pays for when the suspension actively works instead of when it is not. Helping to incentivize design improvements and cost reductions for Hydrop.

To enable service growth, Strömsholmen should further develop traditional product lifecycle services like first line maintenance of Hydrop, but also develop asset efficiency services like data road profile information to inform customers of suspension performance. To interpret usage data, they must improve their service related data processing and interpretation capability. Developing skills to turn product use data into a source of revenue. To better perform product lifecycle services, they need to develop their aftermarket processes and organization. Strömsholmen’s can further grow their service portfolio by moving into process support services in consulting customers with their projects of building a new vehicle. Using these service categories will help Strömsholmen on how it should grow its services over time in a systematic manner. Pursuing services will ultimately make Strömsholmen better prepared to differentiate, to stay competitive, to deepen customer relations and to gain greater profits long-term.

Nevertheless, in order to bundle more services to their products they need to design for product service systems with a life-cycle perspective. That means adapting products specifically for manufacturing, assembly, delivery, use, maintenance and remanufacturing. Adaptations that could greatly reduce costs and create new revenue. Using the life-cycle perspective will allow Strömsholmen to control a larger share of the product value chain thus avoiding sub-optimizing any specific life-cycle phase. In this thesis, analysis of each phase is presented for Hydrop by using Design for X methodologies. For this thesis, that includes Design for Assembly, Design for Disassembly, Design for Serviceability and Design for Remanufacturing. Analysis of each result shows that improvements can be made to Hydrop.

The theoretically minimum part count of Hydrop is presented with 50% fewer components than before. Lowered part count means fewer parts to handle during assembly and disassembly, decreasing the time spent on each activity and simultaneously increasing accuracy. It also leads to a decreased inventory of different components, saving both time and money. Ease of disassembly also increases the chances of being successful within remanufacturing. New disassembly solutions will prevent damage to surface finishes and parts can be used again without additional treatment.

Consequently, Hydrops serviceability is increased by enhanced control of product use. Information about its use from attached sensors can tell about its performance and dialysis can show how clean the oil is, which is directly linked to the function of Hydrop. Along with that, service of internal components will be easier to perform from an improved disassembly sequence.

All of this will help Strömsholmen to be successful with a product service system for Hydrop. Sensors and tools for first-line maintenance will ensure that service is performed when needed to keep the Hydrops in good shape. With great effectiveness in disassembly, Hydrops can easily be examined after use and experience can be
gained about how it is used. It can then be reassembled, with the most expensive components still intact, saving costs, to function in a new product.

As the results show, there are ways to improve Hydrop. Furthermore, the ideas and methods in this thesis could also benefit Strömsholmen in developing future products and services.
11 Recommendations Going Forward

Going forward, Strömsholmen needs to investigate the costs of possible design changes before moving forward with any of the changes. Calculations need to be made on what is gained in assembly time and how manufacturing and overhead costs are affected. Through this, it is possible to make better comparisons on what the design changes will imply before implementation.

Strömsholmen need to further explore the different possibilities with the ideas that are presented, such as the dialysis concept or implementing sensors into the Hydrops. Would the customers allow for sensors to be placed into the Hydrops? Even if they are not in any way online connected?

Another obvious next thing to delve deeper into is design for Product Service System. The work done in this master thesis would benefit from it, which would provide a broader perspective and not only put the focus on Strömsholmen. The customer needs to be involved so that they feel that changes are made with them in the center, and different methods within design for Product Service Systems can provide this.

The results were in this thesis limited to a specific product, Hydrop H5. Using the methods of this thesis applied to other Hydrop products and even other product categories could further help to identify possible redesign improvements, services and innovative PSS business models.

Strömsholmen will be provided with short-format design guidelines based on central themes of this thesis. A synthesis of ideas and methods that can be used to guide Strömsholmen in ideas for future products and services.
References


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### Feasibility Score

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#### SCORING of Questions 1 and 2, ratio of product technology to product life (Answer 1/Answer 2):
- 20/5 30/5
- 15/5 20/10 30/10 30/15
- 10/5 10/10 15/15 30/20 20/15
- 5/5 10/15 15/20 20/20 10/20 20/30
- 5/15 5/10 10/10 30/30 15/15 30/30

#### 3. Value of undifferentiated material (e.g., tin, sheet, pipe, wire) in factory price is:
- less than 20%: +.5
- from 20% to 50%: -.5
- greater than 50%: -2

#### 4. Service, and/or installation is done primarily by:
- service agency (authorized or factory-owned): +1
- independent service agency (e.g., plumber): 0
- knowledgeable user (e.g., in-house mechanic): -.5
- repairable but not currently serviced: -1

#### 5. Transportation costs from manufacturer to user as a fraction of new sales price are:
- less than 2%: +3
- from 2% to 8%: -1
- greater than 8%: -3

#### 6. The average unit price of the (new) product is:
- less than $50 (and the product is either serviced by a knowledgeable user or not at all): -2
- Otherwise: 0

#### 7. Value of current population at replacement cost is:
- less than $200 million: +1
- from $200 million to $1 billion: 2
- greater than $1 billion: 3