ABSTRACT
This paper is a literature review of challenges within the remanufacturing system. The challenges in the remanufacturing system have been categorised in a collection phase, a remanufacturing process phase and a redistribution phase which the challenges have been presented according to. The causes and effects of each challenge have been explored and are presented in this paper. The final result is a compilation figure with the challenges for the whole remanufacturing system. In general, uncertainties and complexity can be seen as the main characteristics for the challenges within the remanufacturing system.

Keywords: Remanufacturing, uncertainties, complexity, literature review.

1. BACKGROUND
Remanufacturing is an industrial process where used products are restored to an 'as-new quality' [1, 2]. Used products are often collected from a large amount of sources [3]. The used products then go through a remanufacturing process with different remanufacturing operations like for example inspection, cleaning, disassembly, component reprocessing, reassembly and testing [4]. The remanufactured products are then often distributed to a large amount of customers [3].

A generic picture of a remanufacturing system is shown in Figure 1. Within a remanufacturing system the customer can also be the supplier of the used product [5].

Figure 1: The remanufacturing system. Modified from: Östlin [5]

As can be seen in Figure 1 there is distinction made between the remanufacturing process and the remanufacturing system. In this paper the definitions by Östlin [5] will be used. In those definitions Östlin [5] state that the remanufacturing process is the process where the used product is remanufactured while the remanufacturing system is a broader term that also includes collection of the used product and the redistribution of the remanufactured product.

A study by Sundin et al [6] of the Swedish remanufacturing industry showed a wide variety of industry sectors performing remanufacturing. Remanufacturing companies were found in the industry sectors automotive, machinery, computers, toner cartridges, medical industry, wood industry and office furniture.

Remanufacturing is sometimes being referred to as a “win-win-win” situation compared with manufacturing [7]. The customer has to pay less, the remanufacturing companies earn more and the environment profit since fewer new components are needed [7].

Remanufacturing differs to manufacturing in many different ways. For example, there are activities in the remanufacturing process that does not exist in manufacturing. These activities are disassembly, cleaning, inspection and sorting [8]. The level of automation is also low within remanufacturing and the batch sizes are in general small [8].

In remanufacturing the quality, quantity and timing of the used products cannot be controlled as the supply in manufacturing can [3]. This means that production planning for remanufacturing is a difficult task [1, 9].

2. AIM
The aim of this paper is to explore what challenges remanufacturing companies have within their remanufacturing systems. Furthermore, how these challenges are connected to each other will also be explored. This will be achieved by studying remanufacturing research theory.
3. RESEARCH METHODOLOGY

This paper is a literature review of the challenges described in the remanufacturing research theory. The literature for this paper has mainly been searched for in scientific publication databases e.g. Business Source Premier and Emerald.

To find out how the challenges are connected to each other, the causes for the challenges and what subsequent challenges the challenges cause has been explored.

To get an understanding of the context for the challenges, a short presentation of the remanufacturing system has been done. The focus areas for this description are those parts of the remanufacturing system where challenges have been found.

4. THE REMANUFACTURING SYSTEM

In this section a short description of a remanufacturing system and its parts are presented.

4.1 Activities within the remanufacturing system

According to Östlin [5] the remanufacturing system consists of three parts: collection, remanufacturing process and redistribution. In the collection phase the used products are collected from previous customers [5]. The aim of collection is to make the used products available and to move them to a place where they can be further processed [3]. In the remanufacturing process the used products are transformed to remanufactured products [5]. The activities within the remanufacturing processes can be inspection, cleaning, storage, disassembly, reprocessing, reassembly and testing [4]. In the redistribution phase the remanufactured products are distributed to customers [3, 5].

In Figure 2 the remanufacturing system is illustrated with the three activities collection, remanufacturing process and redistribution.

4.2 Aim of remanufacturing

The aim of remanufacturing is to bring the product quality up to an as new quality [1, 2]. Compared to other product recovery options remanufacturing upgrades the product the most [2]. The reason remanufacturing has a superior quality compared to other product recovery options is that the product is totally dismantled and all components are restored or replaced which involves a lot more work [10, 11]. In Figure 3 it can be seen how quality, warranty and work content distinguishes the product recovery options repair, reconditioning and remanufacturing from each other.

4.3 Motives for remanufacturing

Seitz [12] conducted a literature review of the motives for remanufacturing. The findings from that literature review are coherent with what de Brito and Dekker [13] state as the motivations for companies getting involved in reverse logistics. These motivations were also found to be valid when Sundin [9] investigated seven different remanufacturing companies. Though, Sundin [9] state that direct or indirect the main motivation is always economic reasons. According to Seitz [12] and de Brito and Dekker [13] the different categories of motives are:

- Moral and ethical responsibility
- Environmental and legislation
- Profitability

In a case study conducted by Seitz [12] for remanufacturers within the automotive industry three more specific motivations were stated as the most important by the original equipment manufacturers (OEM). These motivations were: securing spare parts supply and warranty, customer orientation and market share and brand protection.

4.4 Actors within remanufacturing

Within the automotive remanufacturing market there are three different types of companies performing remanufacturing [12, 14]. The first type of company is Original Equipment Manufacturers (OEM) [12, 14]. An OEM can in turn either be a Product Manufacturer or an Original Equipment Supplier (OES) [12]. The second type of company is Independent Remanufacturers (IR) who is not related to the product or the OEM but remanufactures parts that were originally manufactured.
by the OEM [12, 14]. The third type of company is Contracted Remanufacturers who perform services to the OEM [12, 14].

5. CHALLENGES WITHIN THE REMANUFACTURING SYSTEM

In this section challenges within the remanufacturing system are presented. The challenges are divided into collection, remanufacturing process and redistribution, see Figure 2.

5.1 Collection

A compilation of the challenges within the collection phase of the remanufacturing system is illustrated in Figure 4. In that figure it can be seen that there is a problem balancing supply and demand which is caused by uncertainties in both the supply of used products and in the demand of remanufactured products. If a remanufacturing company tries to balance supply and demand they face complicated inventory management and control functions. On the other hand there are storage and disposal costs associated with not trying to balance supply and demand. There are also a large number of sources in a typical remanufacturing system which increases the complexity.

Figure 4: Challenges within the collection phase. Based on Fleischmann et al [1], Thierry et al [2], Fleischmann and Krikke [3], Sundin [9], Guide [10], Östlin et al [15], Guide and van Wassenhove [16].

In the literature about challenges within the collection phase of the remanufacturing system there is a lot of emphasis on a lack of control regarding quantity, quality and timing of the returned products. This lack of control is recognized by for example [1, 2, 3, 9, 10, 15, 16] and is caused by:

- Reflection of the uncertain life of a product [10]
- Product-life cycle stage and the rate of technological change [10, 15]
- The disposer behaviour, which result in a stochastic return pattern. [3, 15]

The uncertainties in the collection phase are also described as the major difference between a traditional production-distribution network and a network like the remanufacturing system by Fleischmann and Krikke [3]. Guide and van Wassenhove [17] state that the handling of the quality, quantity and timing of the returned products is the key for creating a profitable remanufacturing system.

There are also uncertainties regarding the demand of the remanufactured products. This uncertainty is caused by:

- The rate of technical development. The demand for a product might suddenly drop due to the technical development. [15]
- Detailed forecasting is not possible to perform due to uncertainties regarding timing and quantities of the returned products. [15]

To be able to maximize profits a remanufacturing firm wants to balance the number of returns with the demand for remanufactured products to avoid excess stock from building up [10]. The uncertainties in supply and demand make it hard for many remanufacturing companies to balance supply and demand [10]. All companies do not try to balance the supply with demand since the uncertainties in supply and demand makes inventory management and control functions more complicated [10]. The kind of motivation for returns could also affect the situation for the remanufacturing company, since a take-back obligation might give the remanufacturing company an abundance of used products [1]. A survey conducted with 48 remanufacturing companies by Guide [10] showed that more than half of the companies had no control over the timing or the quantity of the returns.

The remanufacturing companies who do not try to balance supply with demand instead dispose excess used products on a regular basis [10]. Excess used products might cost a lot of money and the disposal cost might be high [9, 10]. The storage area needed to store the excess used products is also often expensive [9].

Another challenge is that a remanufacturing firm typically has a large number of sources which means that a remanufacturing firm has to bring together a large number of small volume flows which increases the complexity. [3]

5.2 Remanufacturing process

A compilation of the challenges within the collection phase of the remanufacturing system is illustrated in
The labor intensity is also caused by small batch sizes. The stochastic routing problem is also caused by complicated disassembly operation. In the same figure it can also be seen that the remanufacturing process is labor intensive which is caused the complicated disassembly operation, which is an activity that is not present in a manufacturing process. There are also three other activities that are not present in a manufacturing system: cleaning, inspection and sorting. The labor intensity is also caused by small batch sizes.

Figure 5: Challenges within the remanufacturing process. Based on: Fleischmann et al [1], Sundin [4], Steinhilper [8], Sundin [9], Guide [10], Guide and van Wassenhove [16], Guide and van Wassenhove [17], Sundin et al [18].

As described in section 5.1 the uncertainties regarding quantity, quality and timing of the returned products are the main challenges for the collection phase of the remanufacturing system. The uncertainty in timing and quantity of the returned products also make the remanufacturing process less predictable than an ordinary manufacturing process [17]. This uncertainty makes production planning more difficult [1, 9].

The uncertainty in quality adds challenges to the remanufacturing process in two different ways. Two returned products that are identical might yield a very different set of remanufacturable parts which makes inventory planning and control and purchasing more difficult [10]. This problem is also noticed by Sundin [9] who states that remanufacturing companies often have a large amount of used products, spare parts or half finished products in storage. These parts might be new parts, used products, spare parts, finished goods and WIP [10].

The other challenge that uncertainty in quality causes to the remanufacturing process is stochastic routings. As stated in paragraph 4.1 the activities within the remanufacturing process are inspection, cleaning, storage, disassembly, reprocessing, reassembly and testing. Though there are differences between different products in terms of product design, remanufacturing volumes and process layouts which means that it is not possible to present generic remanufacturing process that is valid for different remanufacturing facilities [4].

Also when looking at one type of product within the same remanufacturing facility the processing steps are to a large degree dependent on the condition of the product. This means that there are no well-determined sequences of production steps within remanufacturing as there are in manufacturing, [1, 4, 10].

Since a product that has been used very intensively also might require intense remanufacturing processing the variance in quality also causes a variance in time to perform each activity [16].

The disassembly process is an especially challenging process within remanufacturing since most products not are designed for disassembly [18]. This lack of consideration for disassembly in the design phase makes the disassembly process very labor intensive and also very variable regarding the required time [10]. This uncertainty regarding time makes it very hard to estimate flow times and setting accurate lead-times is almost impossible [10].

The remanufacturing process is in general approximately three to five times more labor intensive than manufacturing of the same product. There are two different reasons for this labor intensity. First the activities disassembly, cleaning, inspection and sorting are activities that are not present in manufacturing. Secondly the batch sizes are much smaller and the degree of automation is lower than in manufacturing. [8]

In Figure 3 it was also shown that remanufacturing is the most labor intensive product recovery option.

5.3 Redistribution

On the redistribution side there are only small differences between a traditional production-distribution network and a product recovery network. These small differences might be a greater uncertainty in the demand since the product recovery market is more immature and extra complexity in the redistribution because of the potential interaction between redistribution and collection. [3]

The issue with complexity in the redistribution is also mentioned by Guide [10] who states that a typical remanufacturing firm serves a number of small niche markets and use diverse product offerings and strategies to serve these markets, which often are different from each other. Fleischmann and Krikke [3] also state that the recovered products often are distributed to a large number of customers. The complexity is also caused by many different products being in the same supply chain and also being in different phases of the product life-cycle [15].

Regarding the uncertain demand the acceptance for remanufactured products in the marketplace depends a
lot on the perceived difference between remanufactured products and brand new products. This means that finding a market for remanufactured products can be very hard. [2]

A compilation of the challenges within redistribution is shown in Figure 6. As can be seen in that figure there is an extra complexity and a bit more uncertainty regarding the demand in remanufacturing compared to manufacturing.

![Figure 6: Challenges within redistribution. Based on Thierry et al [2], Fleischmann and Krikke [3], Guide [10], Östlin et al [15]](image)

5.4 Summary of challenges
When looking at the challenges presented for the different activities within the remanufacturing system the uncertainties within the collection process are also affecting the remanufacturing process. The uncertainties in quality from the returned products are reflected as stochastic routings in the remanufacturing process. The complicated inventory control that is a challenge in the collection phase is also, together with

![Figure 7: Compilation of challenges within the remanufacturing system. Based on: Fleischmann et al [1], Thierry et al [2], Fleischmann and Krikke [3], Sundin [4], Steinhilper [8], Sundin [9], Guide [10], Östlin et al [15], Guide and van Wassenhove [16], Guide and van Wassenhove [17], Sundin and Bras [18],](image)

challenges within the remanufacturing system is shown in Figure 7.

For the challenges presented in this paper it can be summarised that the main characteristics of the challenges are uncertainties and complexity. In the collection phase the challenges are caused by uncertainties in supply and demand which also causes complexity within the inventory planning. Additional complexity in the collection phase is caused by a large number of suppliers.

In the remanufacturing process the uncertainties in supply causes stochastic routing and variable lead times which in turn makes production planning complex and complicated. In the redistribution phase there is complexity and an uncertain demand.

Though, it is important to remember that the challenges presented in this paper are a general picture of the challenges within the remanufacturing system. When looking into the remanufacturing research theory the challenges that the remanufacturing companies experience are in many cases dependent on the situation for the company.

As explained in section 5.1 some companies try to balance supply and demand and some do not. Those companies who try to balance face a complicated inventory control problem while those companies that not try to balance supply and demand instead face the challenge to regularly dispose excess used products. In section 5.1 it is also described that a take-back obligation might give a remanufacturing company an excess of used products while companies in other situations might have trouble acquiring enough used products.

6. DISCUSSION
In the literature there are also descriptions of other characteristics that affect what challenges a remanufacturing company faces. Some examples of these characteristics will be described in this section.
The business model that the remanufacturing company uses might have an effect. For example [18] state that functional sale reduces the uncertainty regarding returns by giving the remanufacturing better knowledge of the timing and quantity of the return. This is also acknowledged by [2] who states that quantity and timing of the returns are easy to predict at the end of a leasing or rental contract even though the quality still can be uncertain.

How close collaboration the remanufacturing company has with the retailers and distributors also affects the possibility for a remanufacturing company to coordinate the collection of returned products according to [14] and [17]. Different relationships and the effect they have on the situation for the remanufacturing company is deeply discussed by [14].

A type of relationship that also is discussed by [10] and [15] is when the remanufacturing company remanufacture used products that the customer sends to them. Then the challenge with balancing supply and demand does not exist. Though, this might add additional challenges to the production planning.

As described in section 4.4 there different kind of actors performing remanufacturing. In the remanufacturing research theory there are descriptions of specific challenges for OEM (Original Equipment Manufacturers) and IR (Independent Manufacturers). For example [19] and [20] describe how remanufacturing for an OEM might cannibalise on their sale of new products and if they choose not to remanufacture the OEM might lose sales to an IR. As described by [18] in section 5.2, products are often not designed for disassembly. This is something that the OEM has the possibility to change while an IR does not.

The challenges a remanufacturing company faces is also dependent on the product life cycle according to [15] as well as the product characteristics of the remanufactured products, see [21].

7. CONCLUSION
The aim of this paper has been to explore the challenges within the remanufacturing system and how these challenges are connected to each other. This paper has presented a compilation figure of different challenges within the remanufacturing system, see Figure 7. It has also been concluded that uncertainty and complexity are the main characteristics for the challenges presented in this paper.

8. FUTURE RESEARCH
How the challenges differ depending on the situation for a remanufacturing company is something that is a topic for future research. Then it is of course also interesting for future research to investigate how the uncertainty and complexity within the remanufacturing system can be tackled and how the meet the challenges presented in this paper.

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10. REFERENCES


