Bottleneck Management in Industrial Service Operations: A Case Study

Master’s Thesis
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Abstract

Industrial service operations are becoming increasingly important in the modern world, a trend that is described by the term servitization. It is vital to be able to control industrial service operations systematically in order to gain competitive advantage in a world where customer focus is shifting to the services instead of tangible products.

This thesis was written in order to improve the capacity control of a drives service workshop. Before this thesis, the case workshop had quite primitive capacity control that relied on the memory and knowledge of the foremen only. In order to manage the capacity more efficiently, 16 interviews and a literature review were conducted within the context of this study. The focus of the literature review was on servitization, the concept of available-to-promise, theory of constraints, and predictive maintenance.

It was discovered that in this case the workers were the primal constraining factor of the workshop. Thus the new ERP-based capacity control system suggested is based on the amount and skills of the workers at the workshop, adhering to the principles of the theory of constraints. This system improves visibility to the capacity of the workshop and enables utilizing resources better. The result is specific to the case workshop, but could be applied to other similar industrial service workshops with moderate modifications.

Keywords Theory of Constraints, Servitization, Industrial Services, Drive
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**Työn nimi** Pullonkaukalohjaus teollisissa palvelutoiminoissa

**Koulutusohjelma** Tuotantotalous

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**Tiivistelmä**

Teolliset palvelut kasvattavat merkitystään jatkuvasti. Tätä ilmiötä kuvataan käsitteellä palvelullistuminen (*eng. servitization*). Yrityksille on elintärkeää kyettä hallitsemaan palvelutoimintojaan systemaattisesti saavuttaakseen kilpailuetua maailmassa, jossa asiakkaiden kiinnostus on kasvavissa määrin nimenomaan palveluissa aineellisten tuotteiden sijaan.


Kirjallisuuskatsauksia keskityttiin palvelullistumiseen, saatavuuskyselyyn (*eng. available-to-promise*-käsitteeseen), kapeikkoajattelun teoriaan (*eng. theory of constraints*) sekä ennustavaan kunnossapitoon (*eng. predictive maintenance*).


**Avainsanat** Kapeikkoajattelu, Palvelullistuminen, Teolliset palvelut, Taajuusmuuttaja
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List of abbreviations

5FS = Five Focusing Steps
ATP = Available-to-promise
CCC = Customer Configuration Center
DBR = Drum-buffer-rope
IOT = Internet of Things
JIT = Just-in-time
MPS = Master Production Schedule
MRP = Material Requirements Planning
OPT = Optimized Production Technology
TA = Throughput Accounting
TOC = Theory of Constraints
TP = Thinking Process
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Katriina Suojala
1 Introduction

Drives industry is one of the most important employers in the greater Helsinki area and among the technical students of Otaniemi. Many future engineers have started their careers by building, testing or otherwise working on drives. For those of us studying in Otaniemi, drives industry is often the first one we learn about in practice and thus holds a special importance for many. If not in any other way, then at least as a memory of one’s first “real job”.

AC drives production is an industry worth over 13 billion euros globally, with over 60% of the revenues deriving from Asia-Pacific area. The growth of the industry has been estimated to be around 4.9% (CAGR) for the time period of 2014-2019, continuing a steady trend of growth in the 2010s. The global market is relatively consolidated and dominated by a few large players: Siemens Aktiengesellschaft, Mitsubishi Electric, ABB Ltd., and Rockwell Automation, Inc. Among these four, ABB Ltd. employs most people in Finland with its workforce of approximately 5 000 people. (MarketLine, 2014a)

The degree of rivalry within the business is moderate. There are no extremely high entry nor exit barriers, but the reputation and size of the existing companies discourage many from entering the market. Technology-wise ac drives are relatively straightforward to design and produce, and there are multiple suppliers and buyers of the parts and products in the market. The purpose and required actions of an ac drive remain nearly constant, though the industry’s potentially most significant change in decades is still to come in the form of smarter, connected devices. (MarketLine, 2014a; Porter & Heppelmann, 2015)

This study is centered on a specific drives service workshop and its capacity control. Before this study, the capacity control of the case workshop was quite primitive. The foremen relied on their memory and professional skills in order to handle all the requests and tasks performed at the workshop. There was no theoretical maximum capacity in existence. This naturally caused problems when one or both of the foremen were unavailable for discussion or work. Other departments within the company had no way of knowing the actual situation at the workshop without inquiring it from the workmen, thus also occupying their work time.

In order to solve this issue, a master’s thesis on the subject was requested by the company. A case study approach was best suited for the study. The literature review discusses the concepts of servitization,
available-to-promise, predictive maintenance and the theory of constraints. All the concepts are widely accepted tools for gaining understanding of industrial processes. Alongside the literature review, 16 interviews were conducted. These interviews focused on the operations within and around the workshop, with multiple interviews with the workshop personnel in order to gain the best possible understanding of the actual situation.

The findings are discussed mainly in terms of theory of constraints, a management philosophy focused on streamlining industrial processes. Within the workshop environment, a straightforward process constraint was challenging if not impossible to discover. Thus the most logical conclusion was to address the single constant factor at the workshop, the labour, and manage the capacity of the workshop through it. Wernerfelt (1984) has argued that the resources a company possesses may actually be the cause of their success or downfall, and mentions labour as one of those resources. In this case, managing labour signifies managing capacity, since workers of the workshop constituted the largest constraint to the operations.

This study offers a solution to the issue of controlling capacity at an industrial drives service workshop. A technical solution based on the amount of workers and their skills is suggested. The solution is tailored to the specific workshop researched for this study, but could be applied to other similar industrial service workshops with moderate modifications.

1.1 Aim, research questions and framing

This thesis aims to improve the capacity control of a drives service workshop by identifying the major constraints present in the system and by suggesting capacity control measures to be taken based on these observations.

The issue in need of solving was framed as the issue of resource management by the case company: some orders should be confirmed based on the actual capacity situation, and workload should be observable based on the actual situation at the workshop. The underlying logic of this system should be based on a resource such as workers, teams, work areas, and so on. In order to discover the central resource to observe, a focused research into Drives Service operations and planning was needed in order to find out which are the resources that need to be observed and measured, which resources give
a sufficient view of the whole workload, and which changes need to be made in order to realise these plans.

Thus it was suggested by the company that this study would discuss the following points:

- Which order types and tasks should be observed in order to create sufficient understanding of the current workload
- A system or a tool enabling this observation
- A suggestion of a resource that could be used as the guiding parameter in the system, i.e., a process constraint
- A suggestion on how this tool could aid in confirming orders based on capacity
- A view on which changes would be needed in the IT system in order to implement the changes discussed above

Based on these requirements, the primary research question answered in this thesis is formulated as following:

1. How could the capacity of drives service workshop processes be managed more efficiently?

Two sub-questions were chosen to support this primary research question:

1A. Which resources should be monitored in order to make capacity control more efficient for each process within the workshop?

1B. What kind of changes in the use of ERP software would be required for the case company in order to realize the improvements in capacity control?

This thesis will focus in the capacity control of one drives service workshop and does not suggest specific solutions for other similar workshops, even though the results could be applied for other workshops with moderate modifications. The warehouse operations such as spare part deliveries at the same location as the workshop will be omitted. This thesis will discuss only the Finnish operations of the case company’s drives services and will not consider the case company’s similar processes abroad nor suggest solutions for them.
1.2 Structure of the thesis

This thesis consists of a literature review, discussion on methods and methodology, case company introduction, research problem introduction, solution to the research problem and discussion on the case. The literature review will commence with a look on the servitization, an industry-wide trend of focusing increasingly more on intangible services offered alongside tangible products. It will be followed by a look on the concept of Available-to-Promise, which is central to capacity control and production planning. Following this, Theory of Constraints will be discussed. Predictive maintenance will be shortly introduced at the end of the literature review in order to discuss the future outlooks of the industry.

After literature review, the methods and methodology applied in this case will be discussed. Then the case company and workshop will be introduced, alongside with the current operations planning processes. After introducing the research problem, the solution is presented. The chapter on solution to the research problem follows a framework created for the purposes of this study: it will first discuss how capacity control should be included in the processes of the workshop, then which parameters the system should include, and thirdly what the technical execution should be like. These three steps will constitute the complete solution and are followed by a chapter on how the operations of the workshop are transformed after implementing the solution. Finally the chapter titled “Discussion on the case” will speculate on the potential future state of the industrial service operations and address the unusual process constraint discovered in this case study, followed by suggested next steps on the topic and evaluation of the study.
2 Literature Review

This part of the thesis will discuss literature concerning the subject of this thesis. First there will be a look on servitization, a widespread phenomenon in the manufacturing industry and one that is closely related to the service business of the case company. The next chapter will address the concept of available-to-promise in the manufacturing industries. The third part of the literature review will discuss the theory of constraints, an encompassing management philosophy that solves the problem of distributing capacity, and finally the fourth and final chapter will address the concept of predictive maintenance.

2.1 Servitization

This part of the literature review will introduce a notable concept of the 20th and 21st century: servitization. First the background of the phenomenon will be discussed, followed by a chapter discussing the concept more closely and the reasons a company might have to servitize. Finally there will be a chapter on the discussion concerning servitization: how it happens and whether it is beneficial for a company to servitize in light of the academic literature.

2.1.1 Background

In order to understand servitization, one must first understand what service means. Moeller (2010) notes that service differs from manufactured products based on four attributes; services are intangible, heterogeneous, inseparable, and perishable. Another way to explain the concept can be found from Baines et al. (2008), who defined service as “economic activity that does not result in ownership of a tangible asset”. A similar explanation was given by Angelis et al. in 2011; they defined services as “activities or performance provided to satisfy customer needs, whereas goods are tangible products or stable intangible assets”. Martin and Horne (1991) also made a clear distinction between services and products based mainly on their tangibility. According to them, products are tangible and concrete, and services intangible and abstract. Tangible and intangible seem often the most obvious way to separate products from services.
Service industry, or the industry offering these intangible products, has grown significantly during the 21st century. In the United States, the leader of economic development in the 21st century, the sector has grown from 58.1% in 1960 to 78.6% in 2005. Over this time period, similar development has been seen in a multitude of developed countries: UK’s service sector grew from 49.2% to 77%, France’s from 40.7% to 73.4%, and closest to Finland, Sweden’s service industry grew from 44.6% in 1960 to 75.6% in 2005. Presently most Western economies rely mostly on service. (Heineke & Davis, 2007; Nijssen et al., 2006)

While developed economies have started to shift from manufacturing towards service, the manufacturing companies still operating in these countries have started to look for ways to compete with lower cost economies, and offering industrial services is one of the methods adapted (Baines et al., 2009). Chase and Erikson noted already in 1988 that successful companies both abroad and in their home country, USA, were the ones providing good service with their products. Lele & Karmarkar and DeBruicker & Summe had also published articles on the importance of service for the manufacturing companies in the Harvard Business Review in 1983 and 1985 respectively. It is obvious that service provided by manufacturers was gaining interest, and it was only a matter of time before an academic actually named the phenomenon of services being bundled with manufactured products.

The term servitization was first introduced by Vandermerwe and Rada in 1988. In the early phases of the academic interest, services were mostly analyzed from the marketing perspective. Services were seen as an “add-on” to the existing tangible products, meant to obtain information from customers and to react to their changing needs (Baines et al., 2008; Turunen, 2013). After the concept was introduced, over a hundred papers concerning servitization or concepts closely related to it have been published (Baines et al., 2008). The focus has later shifted from marketing towards operations management approach (Turunen, 2013), but there are still five distinct academic communities contributing to the servitization research: services marketing, service management, operations management, product-service systems, and service science (Lightfoot et al., 2012). Services have become an inseparable part of industrial products, and thus the studies on the subject have also become more diverse and encompass more academic areas.
Turunen (2013) presents the transformation of companies manufacturing tangible products into offerings of tangible product and intangible service as a framework of the scale of offering and time. According to her, the initial state before servitization is represented by companies manufacturing tangible products with no added services. Eventually spare parts and repairs were integrated into the sales process, followed by preventive maintenance, which later turned into long-term maintenance contracts based on transactions. The final stage of this process is the concept of outcome-based contracts, where the service provider takes responsibility for the functionality of the equipment serviced, and the customer simply pays for the outcome of the process. Naturally not all companies need to reach the highest step, but the modern prevalence of service in industrial offerings has created a need for understanding how to include service in the company’s products, what to include and to whom the service should be offered to. Service should no longer be viewed as a separate category for a company, but as a vital component of its strategic mission and corporate planning (Vandermerwe & Rada, 1988).

Figure 1: Development of service offerings in manufacturing firms, Turunen, 2013
2.1.2 Concept of Servitization

This chapter will first strive to clarify the concept of servitization to the reader. First the concept of servitization will be defined, followed by a chapter discussing the reasons for a company to servitize.

2.1.2.1 Defining servitization

Servitization (sometimes termed “servitisation” or “servicisation”) has multiple definitions. Originally Vandermerwe and Rada (1988) defined servitization as “the increased offerings of fuller market packages or ‘bundles’ of customer focused combinations of goods, services, support, self-service and knowledge in order to add value to core product offerings”. 20 years later, in an encompassing study of the servitization literature, Baines et al. (2008) defined servitization as “the innovation of an organisation’s capabilities and processes to shift from selling products to selling integrated products and services that deliver value in use.”, or even more simply, as “creating value by adding services to products.”. A key feature in servitization is customer centricity (Baines et al., 2009). Companies provide customers with encompassing solutions instead of merely manufactured products, and relationships with customers become increasingly important.

Oliva and Kallenberg (2003) have created a framework aimed at explaining a company’s position in the product-service scale. According to them, companies’ offering profiles from manufacturers to service providers can be described as a continuum, and servitization does not mean that each and every company will transform into a service-based organization. They have suggested that servitization simply means companies moving to the right on the horizontal axis that displays the importance of tangible products versus services. In order for companies to transform into service organizations, Oliva and Kallenberg proposed a four-step program:

1. **Consolidating the product-related service offering.** This means bringing different services that support and sell company’s product together into one organizational unit capable of creating unified plans and strategic guidelines.

2. **Entering the installed base market.** Installed base, or the products already sold and installed by the company, are a market that companies should aim to exploit. First, however, they should set up structures and processes to support this goal. When companies move on the horizontal axis, they must accept that they are moving towards business areas they do not necessarily have
experience in. Thus creating solid structures, managing the transformation and learning by doing are vital at this point.

3. **Expanding the installed base service offering.** Once the structures are set up and stabilized, companies should seek to change their service contracts from transaction-based to relationship-based in order to create a more service-oriented organization. By creating a relationship-based service contract with customers, companies can establish and maintain a more lasting relationship. Service providers should also seek to modify their value proposition from a working machine sold to the customer towards the emphasis on product’s efficiency and effectiveness within the end-user’s process.

4. **Taking over the end-user’s operations.** The service provider would take over all the operations of the machinery they sold and invoice the use of it. This step has also been called “advanced services”, or services that are critical to the customer’s core business processes and produced by the manufacturer (Baines & Ligthfoot, 2013).

Even though the four steps above can be seen as a potential rough guideline for companies to servitize, these four steps need not to be taken by all companies. The fourth one did not have any actual examples found in the research by Oliva & Kallenberg. However, a study conducted by Windahl et al. (2004) presented an example within the ABB group. ABB Facilities Management provided their customer with a system that was able to dramatically reduce energy expenditures. The customer judged that ABB could run the system more efficiently than they could, and the companies settled upon an agreement which dictated that ABB would receive a percentage of the energy savings on the condition that they financed the investment. Considering that ABB group has been a strong forerunner on the servitization front with close relationships to their customers and customization of solutions (Miller et al., 2002), the study by Windahl et al. might give indication that Oliva and Kallenberg’s framework reflects reality in at least some cases.
Figure 2: Product-service continuum, Oliva & Kallenberg, 2003

Figure 3: Servitization process as perceived in the literature, Turunen, 2013
Turunen (2013) also offered a framework on how manufacturing companies have embraced servitization according to literature. This framework offers another view to Oliva and Kallenberg’s servitization process. According to her, with time servitization has advanced with customer orientation growing simultaneously. In the earliest phase of industrial revolution, most companies could have been seen merely as manufacturers, selling tangible products to their customers. The following more customer-oriented phases were providing after sales services and then offering maintenance, or entering the installed base market as Oliva and Kallenberg’s described the phase. The final steps towards customer orientation, “Solution provider” and “Outsourcing partner” represent a whole new way to perceive customer relationships with first the emphasis on the sold product being replaced by the offering of product and service, and finally simply the service, with the customer outsourcing their problems requiring solutions to the company providing them. This final step closely reminds Oliva and Kallenberg’s 2003 step number four, taking over the end-user’s operations.

2.1.2.2 Reasons for a company to servitize

Ever since the term servitization was first introduced, the reasons for this phenomenon have been a subject of interest. In Vandermerwe’s and Rada’s 1988 paper on servitization, they presented three reasons for the servitization: locking out competitors, locking in customers and increasing the level of differentiation. Later there has been more research into the matter, and Turunen (2013) wrote of four different arguments for the emergence of servitization based on the literature: economic, strategic, competitive, and sustainability focused arguments. These reasonings have expanded the original three further.

Economic arguments are based on the fact that by adding services into an offering, a manufacturer could expect financial benefits. These financial benefits could include e.g., higher profit margins and more stable cash flows from services, since they do not suffer from economic downturns as heavily as tangible products. Strategic reasoning promotes including services into the strategy of a company, implying that companies position themselves differently in the market. Companies can differentiate their offering based on the combination of products and services, and strengthen the relationship with their customers by creating a unique value proposition. Oliva and Kallenberg (2003) also suggested that customers are demanding more service for their products nowadays, making service more of a necessity for manufacturing companies. Competitive reasoning is based on the lock-in effect of customer relationships: service offering is often difficult to imitate and binds companies to the
customers more closely. This dependency creates barriers to competitors. The most recent argument for the servitization is the sustainability focused argument. According to this reasoning, companies should expand the life cycle of their products in the name of environmental concerns, and enable this by engaging in more maintenance and servicing. (Turunen, 2013)

2.1.3 Discussion on Servitization

Even though academic literature has widely recommended servitization as a future path for manufacturing companies, there is still a need for more research on how to conduct servitization within a company (Oliva & Kallenberg, 2003; Neely 2008). Some specific examples have been introduced, but they have mainly focused on large companies supplying high-value capital equipment (Baines et al., 2009).

This may prove problematic, since Neely (2008) has proved that there may be differences on how servitization affects companies based on their size. According to him, smaller companies with 3000 employees or less were able to improve their profits by servitizing their company further, whereas large companies were able to create more revenue but saw less profits. He explained this phenomenon with the servitization paradox. According to this paradox, increased service offering and higher costs may be present without higher returns. In order for servitization to be financially beneficial, companies should be able to better understand how to tackle challenges associated with servitization.

Gebauer et al. (2006) discussed how manufacturing companies struggling to reap the benefits of servitization should proceed. They offered six success factors required for a company to benefit from servitization, namely establishing market-oriented service development and defining a clear service development process, expanding service offerings, starting with product-related services and proceeding to services supporting the client, establishing a relationship marketing, defining a service strategy, establishing a separate service organization with profit-and-loss responsibility, using a performance measurement system that breaks down the service strategy at the employee level, and finally establishing a service culture. According to them, failing to take these six factors into account leads to unsuccessful servitization.

Another view of the same issue was provided by Neely (2008), with relatively similar reasonings for success and/or failure of servitization. He claimed that the most significant challenges when servitizing
a company are the challenges of shifting mindsets (or how to change the mindsets of customers and employees of the company on the purpose and direction of the company) the challenges of timescale (or how to manage long service partnerships), and the challenges of business models/customer offerings (or how to develop customer value proposition). Oliva & Kallenberg (2003) suggest also that companies may not realize the potential of service business. They may still be stuck on the mindset of being a manufacturer, or wanting to focus on their core competences and ignoring the potential for more business. Similar challenges have also been expressed by Baines et al. (2009) by dividing the most significant issues with servitization of a company as service design, organisational strategy and organisational transformation. According to them, designing services is by nature quite challenging, since they are fuzzy and difficult to define. Like Neely, Baines et al. also recognize that the organization as a whole needs to acquire a new mindset and direction for the servitization to truly fulfill its potential, and that there exists a need for renewed organisational structures and processes. All the papers mentioned above emphasize the need for transformation within the company.

It does not facilitate identifying needed changes that e.g., most supply chain frameworks are inappropriate for services and characteristics of servitized supply chains different than those of “traditional” products, as noted by Johson and Mena (2007). Servitizing a company requires mastering more challenging scenarios and strategies than simply focusing on either manufacturing or services. Turunen (2013) has suggested a way of codifying the change by dividing potential transformation routes within a company into three: traditional, reversed, and partial servitization. Traditional servitization proceeds as has been described in earlier chapters; first the company offers simple services such as repairs and maintenance, and slowly develops its skills towards more advanced services. In reversed servitization, servitization starts from advanced services with after-sales services adopted later. Partial servitization implies changing only the parts of an organization suitable for it; servitization may happen as a fractional change, and only some divisions are transformed. Reversed and partial servitization challenge the traditional, linear view of servitization as the only possible way to servitize and open up more research streams to examine.

2.2 Available-to-promise

This part of the thesis will present the concept of available-to-promise in connection with the manufacturing industry. First the concept will be defined. Following that, some techniques for
calculating available-to-promise are presented. The final chapter of this part will briefly discuss the concept in regards to the academic world and real-life examples.

2.2.1 Concept of Available-to-promise

Framinan and Leisten (2010) have divided a company’s activities concerning customer orders into three different parts: order capture (or initial customer requests, negotiations and finally order placing), production planning (or all activities conducted after the order has been received but before the production begins), and order execution (or actually manufacturing the product required by the customer). Available-to-promise (ATP) deals with the first part: order capture.

ATP is a concept designed for companies to coordinate production schedules with order promising (Jacobs et al., 2011). Framinan and Leisten (2009) have defined ATP as “a number of managerial decisions related to order capture activities in a company, including order acceptance/rejection, due date setting, and order scheduling“. It is the logic through which one can, as can be inferred from the name, provide a response to customer order requests based on resource availability (Simchi-Levi et al., 2004). Nowadays ATP consists mostly of a software system embedded into the company’s resource planning system. Main decisions it carries out are (as described above) order acceptance/selection (OAS), due date assignment (DDA), and order scheduling (OS). ATP systems should be able to calculate whether products can be manufactured and how the manufacturing can be planned so that it is realistic. (Framinan & Leisten, 2010)

ATP systems can be divided into two different categories based on the logic they operate on: push-based ATP and pull-based ATP. Push-based ATP systems rely on demand forecast when pre-allocating resources. Pull-based systems, on the other hand, plan resource allocation dynamically based on actual customer orders received. ATP can also be divided into two parts based on its working logic: batch mode ATP and real-time mode ATP. Batch mode of ATP collects orders from a certain time interval before conducting its calculations and returning an answer to the customer. Real-time ATP is triggered by each new customer order. (Simchi-Levi et al., 2004)
2.2.2 Calculating Available-to-promise

Due to ambiguity in the terminology used in the research of ATP, many different scenarios and definitions for the ATP system modelling have been introduced. Framinan and Leisten (2010) studied multiple models for ATP decision making and concluded that they could be divided into six different classes based on how they approach the ATP’s three major decisions: order acceptance/selection (OAS), due date assignment (DDA), and order scheduling (OS).

1. Upon receipt of the quantities requested by the customers, all three decisions of ATP systems are taken simultaneously.
2. The overall problem is decomposed into job acceptance/selection decisions (where the set of jobs to be accepted is obtained as output), and DDA and OS decisions are taken simultaneously.
3. The three decisions are handled separately. First acceptance/selection decisions are taken, then due dates are quoted, and, in a later stage, jobs are scheduled.
4. OAS and DDA are simultaneously solved. The accepted jobs and their corresponding due dates are scheduled in a subsequent stage.
5. There is no DDA, as it is assumed that the customers’ requests for products consist of quantities plus due dates. The remaining decisions (i.e., OAS) and scheduling are taken separately.
6. There is no DDA, as it is considered that the customers’ requests for products consist of quantities plus due dates. The decision (jointly taken) is which jobs to accept according to the due dates provided exogenously, and how to schedule them.

These six approaches were placed in a two-dimensional framework with the level of integration of decisions on one axis and binary measure of due dates existing or no due dates existing on the other axis.

Modern ATP calculations are conducted on computers as a part of the company’s enterprise resource planning (ERP) system, a commercial software used to control the company’s production. Depending on the mode of ATP used, the underlying algorithm will differ, but many of them rely on linear programming problems (e.g., deterministic optimization-based push ATP models), sometimes adding the stochastic element in order to forecast demand (e.g., stochastic push ATP models). (Simchi-Levi et al., 2004)
However, in order to clarify the underlying logic of ATP, I shall present a more simple calculation method reflecting the logic of ATP. This could be seen as the conventional ATP, and the more complex models as advanced ATP.

Jacobs et al. (2011) divided this calculation into two separate logics and methods of conducting it: discrete ATP and cumulative ATP. With discrete ATP logic, the first observation period and the following periods are all considered independent. With cumulative ATP, different periods are tied together more closely; units promised for orders can be carried on from one batch to the next. These methods lead to different end results of ATP, with neither outperforming the other under all circumstances.

A closely related concept of ATP is Master Production Schedule (MPS). It indicates the correct lot size and timing for production, and calculations made for ATP are based on this schedule (Jacobs et al.,
2011). The simplest way to describe MPS is to say that it instructs what to produce and when to produce it. According to Jacobs et al. (2011), MPS can be calculated with the help of ATP with the following formula:

(1) Calculate available inventory, defined as

\[
\text{Projected available inventory} = \text{Previous available inventory} + \text{Master production schedule} - \text{MAX(Forecast, Actual orders)}.
\]

This calculation is carried out for every period in the planning horizon.

(2) Then carry out the ATP calculations, according to the logic you wish to follow:

(2) A. Discrete logic:
For first period, ATP = On-hand amount of products + MPS - Sum of the orders until the next MPS. For each period when a subsequent MPS occurs, ATP = MPS - Sum of the orders until the next MPS.

(2) B. Cumulative logic:
For first period, ATP = On-hand amount of products + MPS - Sum of the orders until the next MPS. For each period when a subsequent MPS occurs, ATP = Previous ATP + MPS - Sum of the orders until the next MPS.

In order to further clarify the concept of ATP to the reader, consider the following example of a company’s production:
Values calculated based on the formulas above can be found on the rows named “Projected available inventory” and “Available-to-promise”. “Actual orders” in the table refer to orders received at the beginning of the first observation period.

One can notice that there is only one value that differs in the two tables: that of ATP after the MPS batch. Since cumulative ATP takes into account also the earlier ATP, the value is larger. This calculation is effortless to compute and can be expanded easily into products consisting of few different components. However, for more complex environments, modern ATP software systems are much more suitable.
2.2.3 Discussion on Available-to-promise

The importance of ATP rose in the latter half of 20th century with the emergence of truly global economy and technological advancements enabling fast communication. With Make-to-Stock (MTS) transforming into Make-to-Order (MTO) or Assemble-to-Order (ATO) within many industries, availability became harder and harder to forecast with the more extensive product mixes and smaller lot sizes. Nowadays the attributes of the industry demand different ATP models; Simchi-Levi et al. (2004) suggested that the factors influencing the choice include front-end factors such as order specification flexibility and customer response time, back-end factors such as product variety and resource commonality, and IT infrastructure factors such as the choice of ERP. The ATP options available include numerous different models with batch or real-time models, different resource availability levels, pull and push systems and so on (Pibernik, 2005). It is obvious that these conditions can results in such numerous different models that many companies simply choose the simplest possible solution, even if some other was more suitable to them. (Simchi-Levi et al., 2004)

Initially most of the interest on ATP was focused simply on the desired attributes of the ATP systems (Chen et al., 2001), but during the 21st century more quantitative models have become available. These include e.g., mathematical models presented by Pibernik (2005), Chen et al. (2002), Wu and Liu (2008), and Zhao et al.(2005), but encompassing observations over the whole concept are still rare. Framinan’s and Leisten’s framework (2010) has probably been the most comprehensive view on ATP, and even they admitted that they could not discuss all models due to the large amount published.

2.3 Theory of Constraints

This part of the thesis will discuss the theory of constraints management philosophy. First there will be a look on the backgrounds and history of the concept. The second chapter will define the concept and discuss its major components more closely, namely the performance measures, logistics paradigm, and the thinking process. Finally there will be a chapter that discusses actual applications of the theory of constraints and the academic discussion concerning the theory of constraints.
2.3.1 Background

Theory of Constraints (TOC) is a management philosophy primarily developed by the late Dr. Eliyahu Goldratt. TOC began its journey as a simple scheduling program to increase output of a chicken coop plant in the 1970s, and has evolved over the years into a branch of management philosophy with over 400 works published on the subject (Watson et al., 2007; Mabin & Balderstone, 2003).

The first form of TOC consisted of a scheduling software program called Optimized Production Technology (OPT). Major successes in the practical use of the program made it popular among corporations, but the system was not without controversy. OPT software operated based on a secret algorithm, which made it impossible for users to fully understand the system and even led to a lawsuit by M&M Mars Company against Goldratt. Goldratt’s approach also broke the conventional custom of pursuing maximum efficiency of work stations. OPT strove to minimize inventories, so working simply for the sake of working was not included in the system. In order to educate the workers and managers in the underlying philosophy of OTP, Goldratt published a book called The Goal in 1984. (Watson et al., 2007)

The Goal sought to explain the efficiency fallacy to its readers and also introduced integral concepts of modern TOC: Five Focusing Steps (5FS) and drum-buffer-rope scheduling methodology (DBR) (Goldratt and Cox, 1984). These concepts are meant to advice in concrete improvements of production and are discussed more closely in the following chapter of this thesis. Two years later, in 1986, Goldratt published his second book on the subject, named The Race, which further explored the themes of the first book.

Goldratt’s book named “It’s not luck” was published in 1994 and introduced even more sophisticated version of TOC with the inclusion of so called Thinking Processes (TP) (Watson et al., 2007). These processes were meant to aid managers in solving hard-to-understand business problems by understanding relationships between cause and effect. With the publication of “Critical Chain” in 1997, TOC extended into project management and further into a management philosophy. At that point TOC began to gain more friction in the academic world. It has been noted that practically no major literature reviews of TOC applications had been published until 1998 (Mabin & Balderstone, 2003). According to Watson et al. in 2007, more than 50% of all works published on the subject have been published after
1998. These more modern discussions on TOC have solidified its position as a legit management philosophy worth exploring.

2.3.2 Concept of Theory of Constraints

This chapter will strive to explain to the reader what theory of constraints consists of. First there will be a short introduction to the underlying logic of the philosophy, followed by a chapter presenting the original performance measures often discussed in connection with the theory of constraints. Next there will be a chapter introducing the logistics paradigm, or the paradigm for improving the performance of a manufacturing plant of factory. Finally the problem-solving approach termed thinking process will be addressed briefly.

At the bottom of TOC there is the underlying ideology that a company should make money now and in the future (Watson et al, 2007) while fulfilling two necessary conditions. These are

1. providing a satisfying work environment to employees now as well as in the future, and
2. providing satisfaction to the market now as well as in the future. (Gupta & Snyder, 2009)

In the simplest form of TOC, one can condense the idea into three questions:

1. What to change?
2. What to change to?
3. How to cause the change? (Mabin, 1990)

The methodology accepts that there are always limitations to a performance of a system, and that these limitations are usually caused by only one or few elements, termed constraints (Mabin & Balderstone, 2003). It focuses on continual improvement of systems within the context of these constraints (Kim et al., 2008). TOC has a wide variety of potential application areas and is suitable for use in e.g., accounting, scheduling, performance measurement, product mix, quality, and project management and application purposes (Mabin & Balderstone, 2003).

Rahman (1998) and Kim et al. (2008) divide modern TOC roughly into two separate components: logistics paradigm (especially Five Focusing Steps and Drum-Buffer-Rope Scheduling) and thinking
process (a problem-solving approach). They also note that TOC applies performance measures that differ from conventional cost accounting methods, and thus require further discussion in this thesis in order to establish a base for understanding TOC.

2.3.2.1 Performance Measures

TOC focuses especially on increasing the output, not in cost reduction, unlike most of the methodologies of its time (Watson et al., 2007). Financial measures often discussed in the context of profitability of a company are Net Profit (NP), Return on Investment (ROI), and Cash Flow (CF). However, Goldratt insists that these measures are not applicable at the subsystem level (Watson et al., 2007), and introduces three measures of his own for monitoring the production optimality (here applied from Rahman, 1998):

1. Throughput (T) is the amount of output sold. Unsold inventory does not constitute throughput.
2. Inventory (I) is the money that is invested in articles the plant intends to sell.
3. Operating Expense (OE) is money spent by the system in order to turn inventory into throughput.

These measures are part of Throughput Accounting (TA). Throughput, inventory and operating expenses are the “building blocks” of profitability and bind TOC into the three financial measures introduced first in this chapter. The relationships between these six measures can be expressed in the form of simple calculations:

\[ NP = T - OE \]

\[ ROI = NP / I \text{ (Relative Profit)} \]

\[ CF = \text{Cash Received} - \text{Cash Paid} \quad \text{(Laamanen, 2015)} \]

By focusing on the measures introduced by Goldratt, one can improve the more common financial measures through focus on production. As the measures chosen by Goldratt also demonstrate, TOC is very much focused on maximizing corporate profits while discarding unnecessary inventory and operating expenses. According to Rahman (2008), within TOC philosophy the most important goal is
to add throughput, second to lessen inventory and only third to reduce operating expenses, in contrast to most of the traditional management practices which focus particularly on reducing expenses.

2.3.2.2 Logistics Paradigm

This chapter discusses the most influential parts of the logistics toolkit within the frame of TOC: Five Focusing Steps and Drum-Buffer-Rope Scheduling. These methods seek to aid in creating optimal production systems and scheduling according to the philosophy of TOC.

Five focusing steps (5FS) are steps that enable continuous improvement of a system or a process. They are defined as following (adapted from Kim et al, 2008):

1. **Identify the system’s constraint(s).** These constraints usually take the form of physical (resource capacity less than demanded), market (demand less than resource capacity), or policy (formal or informal rules that limit productive capacity of the system) constraints (Watson et al., 2007).

2. **Decide how to exploit the system’s constraint(s).** There is often a way to exploit the constraint more efficiently than it has been exploited until its recognition. E.g., if the constraint is a workstation that is not at use constantly, adding more working hours to the station enables the production to flow more smoothly.

3. **Subordinate everything else to the above decision.** This step commands that all the non-constraining parts of the system must adjust their operation to the constraint. This means, following the previous example, e.g., that even if there is time for a non-constraining workstation to produce more, it should not do it if the constraining workstation cannot absorb the parts produced. If it does, only the amount of inventory grows, which is an undesirable effect.

4. **Elevate the system’s constraint(s).** If the three steps above have been completed and the constraint still constrains production, it should be elevated. In the case of the example used in the steps above, one could e.g., add one more workstation to perform the same duties as the constraining one does.

5. **If in any of the previous steps a constraint is broken, go back to step 1. Do not let inertia become the next constraint.** This step ensures that the improvement truly is continuous. Once the most important constraint has been recognized and addressed, it is time to continue to the next one.
These five steps operate as a guideline for managers to continuously monitor their production system and identify its weaknesses. This process is not a one-time project, but a method for long-term improvements.

The Drum-Buffer-Rope (DBR) Scheduling is a method of production planning in the most optimal way according to TOC. DBR represents a set of rules for implementing the first three of the five focusing steps.

DBR consists of three concepts: the drum, or the constraint, the buffer, or the factor offsetting material release from the constraint, and the rope, the material release mechanism. These concepts can be explained through an example of a manufacturing production line. The drum is the constraining element of the production, e.g. a workstation that every single product must go through before completion, and one that works the slowest. The concept of a buffer can be divided into shipping, time, and capacity buffers, each a strategically placed element of the production in order to ensure its optimal operation. In this example, we can decide that the buffer is an inventory of work-in-progress products awaiting their turn to be handled by the constraining workstation. The rope unites these two concepts together. It ensures that a correct amount of material is released to the production line in relation to the

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Figure 6: Five focusing steps, adapted from Kim et al., 2008

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consumption rate of the constraint. The length of the rope represents the amount of inventory in the production line, and in our example can be understood as the correct amount of raw material inserted to the production line. If there is too little, constraining workstation will run out of material. If there is too much, the buffer will grow unnecessarily large. The rope should define the optimal amount and thus control the production line. (Watson et al., 2007)

2.3.2.3 Thinking Process

Out of the components of TOC presented here, Thinking Process (TP) is the most recent. It enables managers to understand, analyze and solve business problems based on the principles of TOC and thus widened the application possibilities of TOC at the time of its introduction.

TP has five major components in itself, namely

1. Current-reality tree (CRT)
2. Evaporating-cloud logic tree (ECT or EC)
3. Future-reality logic tree (FRT)
4. Prerequisites logic tree (PRT)
5. Transition logic tree (TT)

These trees produce problem-solving diagrams termed logic trees through a codified process of building them. First there is the CRT, a logic tree meant to portray the current situation and connections between the situation’s symptoms, facts, root causes, and core problems. It needs to make the current situation explicitly clear to all who read it. FRT, on the other hand, produces a vision of the future: it shows the desired future state with the help of injections, or ideas and actions needed to reach that state. ECT is used when in need of fresh solutions and ideas; it verbalizes assumptions made by people and enables discussion and understanding of them. PRT aids in creating an action plan to reach desired state by introducing intermediate objectives, or smaller objectives one needs to reach in order to reach the overall goal. Finally TT displays, as its name implies, transitions between different states through actions. (McMullen, 1998)
2.3.3 Discussion on Theory of Constraints

TOC has received both praise and critique over its 37 years of existence. In the beginning TOC was mainly supported by anecdotal evidence and success stories, which made it seem unreliable as an overarching, academically valid ideology. However, presently there are numerous studies proving the validity of TOC.

Mabin and Balderstone published a study about the success of TOC methodology in 2003. They noted in their conclusions that TOC appeared to be a very successful methodology: over 80% of cases studied reported improvements in lead times, cycle times, due-date performance and/or inventory, and within these cases, 40% reported improvements in financial performance. Over 100 examples of real-life applications were studied, and application areas of TOC were highly varied, spanning from military to education and software.

However, TOC has not survived entirely without criticism. It has been claimed by critics that TOC produces solutions that are feasible but not optimal (Watson et al., 2007). Due to the fact that TOC recognizes the actual limitations of a system, a scheduling made according to TOC will not appear as optimal as one made with e.g., Just-in-time production scheduling, which will create optimal but potentially unrealistic schedules. Watson et al. (2007) also note that even though comparisons of TOC with JIT have concluded that TOC performs worse than JIT in term of amount of output and inventory, they have often been made under false assumptions. These studies failed to define procedures for applying TOC and thus could not realistically compare JIT and TOC. According to Watson et al. (2007), a much more comparable review could be made by clearly defining the characteristics of TOC system, which in their opinion has not yet been done. Gupta and Snyder (2009) studied literature comparing TOC with JIT and MRP, and found that the literature acknowledged the importance of TOC while simultaneously also indicating that there is still a need for more analytical and empirical research in order for TOC to prove that it can rival established ideologies such as JIT and MRP.

Throughput Accounting (TA), or the performance measure system introduced by Goldratt, has been criticized e.g., on the account of it having too much ambiguity and trouble with determining correct product cost and price for a product (Watson et al., 2007). The first has been caused by Goldratt’s own slightly ambiguous writing style, and the second criticism he has disavowed: Goldratt did not see product cost as an important measure and necessary for pricing (Watson et al. 2007). Despite criticism,
TA can also be seen to address some issues earlier left untouched, namely the fact that traditional accounting systems had five problematic areas according to Rahman (1998): lack of relevance, cost distortion, inflexibility, subjection to the needs of financial accounting, and impediment to progress in world class manufacturing. According to him, there exists a mismatch between the goal of the company and traditional accounting practices, and this issue can be solved through the application of TOC and TA, which evaluate the effect managerial actions on productivity and profitability more accurately.

Thinking Process (TP) has been criticized for being too subjective to create objective descriptions of problems and their solutions, as well as not being user-friendly enough (Watson et al., 2007). However, e.g., Gattiker and Boyd reported already in 1999 that using TP tools had enabled a company to achieve significant improvements in item availability and customer service. Later, in 2002, Taylor and Sheffield proved that TP could identify employee pay as a constraint to revenue enhancement due to errors in remitting medical claims. There exist numerous more examples, but these two alone have demonstrated that TP tools appear to be helpful outside academia and applicable to real-life situations.

2.4 Predictive Maintenance

This part of the literature review will discuss predictive maintenance. First the concept will be explained to the reader. Next there will be a brief look at the different methods of applying predictive maintenance, and finally a discussion on the recorded results of predictive maintenance.

2.4.1 Concept of Predictive Maintenance

Maintenance, as a concept, is concerned with preventing all losses that are caused by equipment or system related problems (Mobley, 2002). Preventive maintenance is a type of maintenance that aims to reduce down-time of a production plant and costs associated with it by fixing issues with the equipment before they break down. It consists of systematic inspection, detection, correction, and prevention of incipient failures, before they become actual or major failures (Bana e Costa et al., 2011). Predictive maintenance (sometimes termed condition based maintenance) is a subset of this methodology. Carnero (2005) defined predictive maintenance as “a policy in which selected physical parameters associated with an operating machine are sensed, measured and recorded intermittently or continuously for the purpose of reducing, analyzing, comparing and displaying the data and information obtained for support decisions related to the operation and maintenance of the machine”. In other words, unlike with
traditional preventive maintenance, predictive maintenance will not fix equipment simply because a certain time interval has passed. Predictive maintenance seeks to observe the condition of the machine and then decide whether it needs maintenance at a certain time (Ahuja & Khamba, 2008). However, one should note that predictive maintenance alone does not eliminate the need for reactive maintenance (i.e., addressing problems once they arise, not earlier) or preventive maintenance. It requires other maintenance methods to ensure the smooth operation of a plant and simply enhances them.

Mobley (2002) presented a framework that connected value creation with competitiveness while observing the issue from the viewpoint of maintenance. He proposes that the understanding of the importance of maintenance has been growing from simply reactive fixing to a more and more preventive approach. In his framework, predictive maintenance is the more sophisticated version of preventive maintenance and creates more value while simultaneously resulting in more competitive advantage. In order to reach the best possible results, a company should aim even higher, to proactive maintenance. All employees of the company should participate in making maintenance a priority within proactive maintenance mindset. While predictive maintenance might reveal hidden problems undiscovered by preventive maintenance, proactive maintenance would increase overall equipment effectiveness even further by improving the function and design of the production equipment.

Similar four stages of maintenance have also been presented by Swanson (2002), though termed reactive maintenance, proactive maintenance (including both preventive and predictive maintenance) and aggressive maintenance. She noted that each step higher results in more need for training and higher costs, but also in greater improvement of equipment and plant performance. Even though the fourth evolutionary step of maintenance, termed aggressive or proactive maintenance, is proclaimed the most effective, it requires a large amount of time and effort. Considering also that according to Tan & Raghavan (2007) both reactive and preventive maintenance alone are ineffective, predictive maintenance appears to be the first “step” that would be optimal to apply while also having the least cost of the two options available after eliminating reactive and time-based preventive maintenance.
2.4.2 Predictive Maintenance Techniques

Predictive maintenance can be divided into two categories:

1. Statistical-based predictive maintenance, which employs the help of mathematics by recording precise information about the machinery and its breakdowns and then follows a statistical model for predicting failure, and

2. Condition-based predictive maintenance, which concludes that most failures are caused at least indirectly by normal wear of the machinery and could be prevented by observing the signs of wear in components. (Edwards et al., 1998) “Normal wear” consists of e.g., erosion (hydraulic structures, dikes), consumption, and cumulative wear (cutting tools) (Deloux et al., 2008).

These two categories represent different approaches to the same situation. According to Mobley (2002), actual techniques used for monitoring equipments’ condition (approach 2) can be categorized into five major groups: vibration monitoring, process parameter monitoring, thermography, tribology, and
visual inspection. In order to achieve best results, more than one technique for observing machinery should be applied. Vibration monitoring observes vibration of a machine. All machines vibrate while working, and the frequency of vibration can provide a view to the mechanical condition of the machine. Process parameter monitoring observes operating efficiency of the equipment. By knowing the normal efficiency of equipment and then measuring the process parameters of a specific process, it is possible to detect unusual variation in the performance. Thermography is concerned with infra-red energy. Since all objects above zero degrees Kelvin emit energy, it is possible to monitor machinery based on this radiation. Tribology refers to the design and operating dynamics of the bearing-lubrication-rotor support structure of machinery. Two of the most important tribology techniques for monitoring machinery condition are analysing lubricating oil and wear particles. Visual inspection naturally means observing the machine visually and detecting potential problems. Naturally these five do not cover all possibilities for monitoring the condition of a machine. Other examples include e.g., laser alignment corrections and X-ray testing (Szczerbicki & White, 1998). All these techniques provide information about the condition of a certain machine, and give indication whether that specific machine requires maintenance.

2.4.3 Discussion on Predictive Maintenance

According to academic literature, predictive maintenance is quite a successful strategy for maintenance, even if many companies do not exploit it to the fullest. Hashemian and Bean (2011) noted that 30% of industrial equipment is maintained only with time-based and hands-on equipment maintenance, not the technologies developed for predictive maintenance. However, even applying some form of predictive maintenance may e.g., eliminate unnecessary repairs in scheduled maintenance, increase equipment service time, reduce accidental shutdown, increase security, and increase production time (Huang et al., 2005; Carnero 2003). Mobley (2002) provides results of a survey on the effect of predictive maintenance claiming that by applying predictive maintenance methods, unexpected machine failures reduced by 55% in average, the costs associated with maintenance operations were reduced by 50%, and the useful operating life of plant machinery was increased by 30%. The survey was carried out at 500 plants that had implemented predictive maintenance techniques. These results sounds extremely positive, but it should be noted that the methods of conducting the survey were not specified in Mobley’s presentation of the results (e.g., no survey questionnaire was provided), so one cannot be certain how exactly the research was performed. However, even when keeping this fact in mind, predictive maintenance programs appear to result in positive overall changes.
Carnero (2005) also presented a wide variety of positive effects of introducing predictive maintenance, including best scheduling of maintenance actions and enabling the effective scheduling of supplies and staff, an increase in the safety of the factory, and reduction of direct maintenance costs. In her earlier study from 2002, Carnero also noted similar positive effects, but emphasised also the more challenging aspects of predictive maintenance in the form of a case study: choosing wrong methods for predictive maintenance observation can lead to failure of setting up the system and caused economic losses. Similar failure of implementing predictive maintenance was reported by McKone and Weiss (2002). In their example, a US manufacturer of nylon fiber replaced their reactive maintenance with predictive, but due to the lack of diagnostic skills of the maintenance technicians, maintenance costs actually increased initially. These examples demonstrate why thorough investigation into the technique is required before implementation. As a result of this need for expertise, the process is sometimes outsourced.

Swanson (2002) conducted a research into the effect of different maintenance strategies’ effect on the plant performance. Her findings supported the views held by earlier literature: companies applying simply reactive maintenance performed worse than those applying more sophisticated maintenance methods, such as predictive maintenance. This also indicates that predictive maintenance is a worthwhile maintenance approach to implement.

Challenges of predictive maintenance include those of statistical modeling and the complexity and cost of implementing predictive maintenance. Due to the fact that there is not a commonly accepted, widely applicable statistical model available, predictive maintenance still generates only as favourable results as the statistical models allows it to. This issue is one that requires more mathematical modeling and wider research. The second issue has to do with fact that implementing predictive maintenance requires advanced monitoring technologies, real-time data acquisition systems with sophisticated data storage and speed requirements and signal processing techniques. However, with the development of modern technology, this problem can be expected to disappear slowly but surely. (Tan & Raghavan, 2007)
2.5 Synthesis of the literature review

This chapter discussed four core concepts of the literature concerning the topics of this study: servitization, available-to-promise, theory of constraints, and predictive maintenance. Servitization offers a wider outlook to the current situation at the industrial drive business: companies are focusing increasingly in services, their quality and uniqueness. The concept of available-to-promise discusses how customer orders are addressed when they arrive and delivery promised to the customer based on the actual workload of the factory or workshop. Theory of constraints is a management philosophy that puts emphasis on discovering the constraints of a process and addressing them, thus creating a more efficient process. Finally, predictive maintenance is a type of maintenance that might become a trend in the future. With predictive maintenance, units are not repaired only once they break or based on a schedule, but based on the actual condition of the unit.

The next chapters of this study will discuss the case, starting with discussion on the methods and methodology applied in the research. Next, the case company will be introduced, followed by the introduction and solution to the research problem. Finally there will be a discussion on the case.
3 Methods and Methodology

This chapter will discuss the methods and methodology used in this study and their validity in academic writing. It will present the major elements and attributes of case studies first and then discussion surrounding them. After this, there will be a closer look on the execution of this specific study.

This thesis is a single-case study with both qualitative and quantitative methods used in the processing of information and in reaching conclusions. Case study is a strategy meant for research that wishes to explore the dynamics of certain settings (Eisenhardt, 1989). It generates theory based on findings of an actual case. Case study is remarkably different from traditional hypothesis-driven studies especially in the sense that it is inductive, not deductive; no hypothesis is created before sampling, gathering data, or processing it (Brax, 2015). As a result of this, the theory generated is often novel, testable, and empirically valid (Eisenhardt, 1989).

Eisenhardt proposed an 8-step process of theory building through case studies in 1989. The eight steps mentioned are

1. Getting Started - definition of a research question
2. Selecting cases - specified population with theoretical, not random population
3. Crafting instruments and protocols - multiple data collection methods, qualitative and quantitative combined
4. Entering the Field - overlapping data collection and analysis
5. Analyzing data - within-case analysis
6. Shaping hypotheses - iterative tabulation of evidence for each
7. Enfolding Literature - comparison with conflicting and similar literature
8. Reaching Closure - theoretical saturation when possible (Eisenhardt, 1989)

The final, eight step might not be relevant for this thesis, since this thesis is not meant to be a peer-reviewed academic paper. It should also be noted that the process presented is not straightforward, but iterative. Thus returning steps backwards before continuing forward is possible and probable during the research process, since the theory is generated through iteration.
Despite case studies becoming the most popular qualitative research strategy (Piekkari et al., 2009), there are still objections to their applicability in scientific research. Some complaints include e.g., generalizing theory from cases that may not be representative (i.e. no random sampling), interviews as a source of information, and the challenges of presenting empirical evidence within the context of case studies (Eisenhardt & Graebner, 2007).

However, these issues mainly arise through misunderstanding of the concept of a case study, possibly aided by unclear writing or research design of the researcher. A case does not need to be randomly selected, since it does not need to confirm a theory known beforehand. The purpose of a case study is to develop a theory, not to test it. The risk of interviewees answering certain questions certain ways merely to “look good” can be mitigated through the use of data collection techniques that limit bias as much as possible. By choosing numerous interviewees who view the issue at hand from many angles, e.g., with differences in age, corporate division, or hierarchical level, or by combining present and retrospect cases, the human factor can be diminished. In order to present qualitative data, it cannot be simply contained to a table, as is in the case of qualitative research. However, by compiling a relatively complete rendering of the case at hand and by intertwining it with the claims made by the author, a clearer correlation can be displayed. (Eisenhardt & Graebner, 2007)

In order to make the research and writing of this study as efficient and structured as possible, a schedule was created by the writer in the beginning of the research. It was agreed with the instructors that there would be a monthly check-up meeting where the advancement of the study would be discussed and goals be set for the next month. The schedule can be seen in figure 8. This figure is from the fifth check-up, since the “active” meeting time is always in red and the points already passed in grey. The schedule was divided into four major phases: theory research, i.e., researching and writing the literature review, interviews, i.e., conducting the interviews and exploring the company, analysis, i.e., understanding the problem and planning a solution, and finishing, i.e., finishing the thesis and making corrections based on feedback. The schedule worked well and there were no delays nor problems meeting the deadlines at any time during the study.

Literature review was conducted by the traditional format of reading multiple academic papers and forming an understanding on the topic through them. The topics were divided by weeks, indicating that one week was reserved to studying servitization, one for theory of constraints, etc. This made it easier to look for sources and to concentrate on one subject at a time. The literature was reviewed again after
the writer’s understanding of the research problem was deepened and thus had some revisions in the analysis phase of the study.

![Master's thesis schedule, example form the fifth checkup on 5.7.2016](image)

The interview questions of the study were based on the knowledge gained from the literature review. The interviews were all conducted in Finnish. Due to the sensitivity of the topic the interviewees remain anonymous. However, a list of the interviewees’ positions and dates they were interviewed can be found in appendix I. The interview questions were initially divided into three different parts: questions about servitization, questions about ATP, and questions about TOC. The questionnaire can be found in appendix IV. Predictive maintenance questions were mainly aimed at two of the interviewees, a manager of service product management and a master’s thesis worker researching the subject. Thus they were not included in the initial questionnaire, but simply brought up during these two interviews besides other subjects. On the whole, the interviews did not follow the questionnaire after the first two. The subject matters remained the same, but it was found out that straying from the questionnaire and focusing more on the subject matter the interviewee was an expert on (e.g., logistics or customer
service) was more beneficial for understanding the business and its operations. Thus most of the interviews were merely structured conversations around the interviewee’s expertise, not strict questionnaire-filling sessions.

The analysis consisted of combining the information acquired from the academic papers and from the company and seeking to understand the root cause of the issues researched. By understanding what the issue was, the solution could be deduced from it. During this phase multiple meetings and workshops took place. The meetings were held mainly for understanding certain aspects of the business more thoroughly. Once the solution started to form, a workshop was held on 6.6.2016 in order to specify the details of the system offered as a solution. These specifications formed the eventual solution to the research problem and will be presented in chapter six.

The case study approach combined with academic emphasis on servitization and theory of constraints and qualitative interviews fit the research problem quite well. The interviews were necessary in order to understand the business and the root cause of the issues researched; quantitative analysis alone would not have offered much in this specific case, especially since not much data was available due to the rudimentary nature of the current IT system. Industrial service industry is also quite heavily dependent on humans, since services are always tied to people performing them. Thus a more qualitative approach could be seen as a suitable one in order to preserve the unique nature of humans as research subjects. From the academic side, focusing on theory of constraints as the problem-solving approach was a relatively good choice. It did offer insights into what to focus on and aided in creating a structured view of the research problem. On the other hand, theory of constraints mostly focuses on processes concerning manufacturing industry. Industrial service operations differ from manufacturing greatly, making the approach less straightforward. The study required a new look into academic literature in order to disentangle this complexity. However, it should be noted that no simplified academic approach could ever be exactly perfect for a real-life situation, and it actually creates more value to the study academically to successfully apply practices traditionally used in one environment in another. Thus the choice of using theory of constraints as the problem-solving approach can be seen as appropriate for this study.
4  Introduction to the case company

This chapter will briefly introduce the case company and its different functions. It will commence with discussion on the ABB Group as a whole and then focus on the unit this thesis was written for, ABB Drives and Controls Service business unit.

4.1  ABB Group

ABB (www.abb.com) is a leader in power and automation technologies that enable utility, industry, and transport and infrastructure customers to improve their performance while lowering environmental impact. It operates on the global electrical equipment market, which is worth approximately $ 260 billion. The industry is characterized by being dominated by few large companies, including General Electric Company, Schneider Electric SA, ABB, and Alstom SA with intense rivalry between them. Some large players have started to integrate backwards into raw material supply and thus weaken supplier power, and with scattered buyers and relatively low buyer power, their leverage is becoming quite remarkable. Due to the small amount of substitutes available, electrical equipment does not face a large threat of substitution. Overall the entry barriers are high to the market, creating only a moderate threat of new entrants. (MarketLine, 2914b)

ABB itself is divided into five divisions, namely Discrete Automation and Motion, Low Voltage Products, Process Automation, Power Products, and Power Systems. The ABB group of companies operates in roughly 100 countries and employs about 140,000 people. Out of these employees, approximately 5200 are employed in Finland. ABB is one of the largest industrial employers in Finland with plants in Pitäjänmäki (Helsinki), Vuosaari (Helsinki), Vaasa and Porvoo.

In 2015 (the latest fiscal year available) ABB generated a revenue of approximately $ 36B and reached an operational EBITA margin of 11.8%. Out of the five divisions, Power Products generated most revenue (25% of the whole group’s revenue), with other divisions following at 17-24% of revenue generated. Services generated 17% of the total revenues of the company. (ABB Annual Report 2015)
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Drives are machines that convert fixed frequency and voltage power into variable frequency and voltage power for a motor. ABB Drives and Controls manufacturers mainly drives and belongs to Discrete Automation and Motion division within ABB Group. It is one of the world’s leading manufacturers of drives with over 6000 employees in more than 80 countries. Drives and Controls is further divided into four separate units: Low Power Drives and Automations, LV High Power Drives, Medium Voltage Drives, and Drives and Controls Service. This thesis will focus on Drives and Controls Service.

Figure 9: ABB performance, ABB Annual Report 2015

Figure 10: ABB Drives & Controls global presence, ABB 2016
4.2 ABB Drives and Controls Service

ABB Drives and Controls Service offers global service for installation and commissioning, maintenance, repairs, engineering and consulting, energy appraisal, upgrades and retrofits, replacement, spare parts, technical support, service contracts and training to its customers. The unit seeks to maintain or improve customers’ drives’ performance and maximize their lifespan through service.

The service portfolio is divided into four different areas based on customer needs: rapid response (i.e., the sales of spare parts and repairing drive units), operational efficiency (i.e., actions to ensure the drive unit will not break; preventive maintenance), life cycle management (i.e., the options the customer has once the drive unit is reaching the end of its life cycle), and performance improvement (i.e., the updating or changing the purpose of the drive).

In Finland the unit is located in Pitäjänmäki, Helsinki and Kiitoradantie, Vantaa.
5 Introduction to the research problem

This chapter introduces the research problem investigated in this study. First there will be an introduction to the case workshop and its functions, followed by an explanation of the current capacity control processes and the issues concerning them.

5.1 Drives service workshop

The Finnish drives service workshop is located near the Helsinki-Vantaa airport at Kiitoradantie, Vantaa. In April 2016 it was announced that the workshop will be relocated to the drives factory in Pitäjänmäki, Helsinki in 2017. The current location at Kiitoradantie includes a warehouse from which spare parts and product kits are sent all over the world, but this thesis will omit these services and focus merely on the workshop.

Fifteen people are employed at the workshop. They are supervised by two foremen and work for 8 hours a day for five days a week, with the workday beginning between 6.30 am and 9.00 am and ending between 3.00 pm and 6.00 pm, depending on the worker’s own will. The workers are specialized in certain products and processes, but are encouraged to learn constantly more and can be shifted between different departments within moderation.

Products serviced at the location include all drives produced and currently serviced by ABB, with distinctions made based on the production lines. The oldest product lines serviced are titled “Mega” and “Cyclo” product lines. They were originally introduced in the 1980s. More recent product line titles are numbered instead of named. The number increases by time, indicating e.g. that the technology of a drive unit from the product line 600 is older than the technology of a unit from the 800 product line. The latest product line introduced by ABB is the 880 product line of drives. It must be noted that as ABB produces more than one product line at a time, a product line number does not indicate the actual age of the unit, merely how advanced the product’s technology is.

The actions performed at the workshop are numerous. They include repairs of drive units and circuit boards, production of exchange units, handling of defective material returned from the customer, production of retrofit kits, software downloading into drive units, analysis of products as requested by the drives factory at Pitäjänmäki, and production of demo drive units for industry fairs. Three of the
most prominent and common services provided by the workshop are repairs of drive units, production of exchange units and software downloading.

Repairs are mostly performed on drive units, either as fixed price repairs or as price estimation repairs. Circuit board repairs are largely extinct due to newer technologies replacing traditional circuit boards, but the possibility of repairing them at the workshop still exists. Traditionally all repairs have been so-called price estimation repairs, implying that the customer sends the product to the workshop where the workers inspect it and estimate the time and components needed for the repair. This estimation and is sent to the customer, who then decides whether they wish for the unit to be repaired or to be sent back. However, waiting periods for these approvals may get prolonged, and thus a new form of fixed price repair was introduced in 2015. In this case the price of the repair is fixed and the workshop does not need to wait for the customer’s approval for the repair after the unit has been received by the workshop. These fixed price repairs are still limited to a few types of 800 product line drives.

Exchange units are drive units sold in exchange for an older drive unit. The customer sends their defective unit to the workshop and receives a new, functioning one back. This new unit is actually a repaired, used-to-be-defective unit of some other customer and thus cheaper than a brand new drive unit. Incoming defective units are received and inspected, and if deemed suitable, used for the production of exchange units in the future. This is what defective material handling indicates. The customer does not need to wait for the defective unit to reach the workshop; once they indicate their will to purchase an exchange unit, one will be sent to them right away. Exchange unit production can be either MTS or MTO based.

Retrofit kits are kits used to upgrade older units into more modern ones. Using a retrofit kit means that the customer does not need to change the whole unit, but simply adds new functionalities to the existing drive unit. A retrofit kit is collected and partly installed at the workshop. The final installation to the drive unit is done at the place the drive unit is, indicating that there is no need to send the unit to the workshop. Retrofit kits are produced MTO based.

Software downloading is performed daily. A physical place named Customer configuration center (CCC) or the software downloading center is designated for this purpose. In this center, a software controlling the drive unit is installed into a card. Customer configuration is the new process of customizing drive units for the customers. Units are built nearly into completion, but only once a
customer wishes to purchase them, they will be completed. For the products handled at Kiitoradantie presently, this customer-specific action indicates downloading a specialized software, adding optional components, and testing the unit. Software installed into the drive unit, whether it be as part of a CCC process or as part of a traditional repair or production of an exchange unit, is either MTS or MTO based.

Finally there are occasional analysis and demo unit repair tasks as requested by the Pitäjänmäki factory. These tasks are project based and sporadic. Faulty drive units may be sent in for analyzing the root cause of the fault.

The workshop and its workforce are divided into five different groups: “800 department”, “600 department”, “Upstairs”, “Retrofit/Mega/Cyclo”, and “CCC/software downloading”. These names are merely descriptive titles to ease the distinction of different places and actions within the workshop and strictly unofficial. These names are used by the foremen and the workers. The main activities performed by each department and the amount of workers usually working in the departments can be seen in figure 12.

Figure 12: Workshop departments and the tasks they perform
“800 department” describes the department where all activities concerning drive units of the 800 or 880 product lines are performed. All products from these products lines are handled here, whether the service be repairing, producing an exchange unit or anything else. The same principle holds true for the “600 department”. “Upstairs” is the department that handles physically smaller drive units, or those of the 550 and 800 product lines with smaller frame sizes. These units are cheap enough that most customers are unwilling to send their units for repair, instead choosing to purchase either a new one or an exchange unit. “Retrofit/Mega/Cyclo” department produces retrofit kits for upgrading older drive units and specializes in the repair of the Mega and Cyclo product lines. These product lines are quite old and the repairs rare. If the repairs do occur, they are usually large-scale projects. Finally “CCC/software” department handles software downloading. This is the only department that does not have a dedicated worker performing the activities; downloading software is a rotating shift between all the workers of the workshop, so that each member works as a software downloader for a day at a time.

5.2 Workshop operations

This chapter will address the operations and processes as they currently are at the Drives Service workshop and strive to explain how an order proceeds in the system.

Workshop operations commence with an order in the electrical system provided by ABB, titled Business-Online or BOL. A customer makes their order in this system, whether it be repair, ordering spare parts, or other activities requiring the attention of the workshop-warehouse complex at Kiitoradantie. From here on, the order either continues directly to the workshop, or, in case of so-called “stop codes” (such as destination country being one where export is limited to, a specific size or frame, etc.) is handled by the customer service. Customer service may send inquiries or call the workshop foremen in order to clarify what to do with the order and whether it can be accepted. The sales and procurement may also wish to discuss things with foremen, regarding e.g., whether a certain defective material in storage can be used for producing an exchange unit they need. The most common reasons for other ABB departments to contact the foremen are about scheduling, whether a certain product is available, whether an order could be fulfilled earlier, and whether a certain unit could be analyzed. Foremen receive numerous inquiries daily.

After the order has been confirmed, a customer receives a notification of this and sends their defective material for repair or in exchange for a new exchange unit. Once the unit has reached Kiitoradantie, the
department receiving shipments will register the unit as having arrived and marks the workshop lead
time starting from that moment. The lead time is constant and does not depend on the actual capacity
situation at the workshop. As the units can be operated on only once they arrive, there is not a great
deal of visibility to the future workload of the workshop. An approval for a repair or a new unit requiring
attention might arrive at any time, which makes operations planning challenging at the workshop.

After this the order becomes visible in the workshop’s work queue. The work queue transaction of SAP
is the most important part of the operations planning (and thus capacity control) within the workshop.
SAP is an ERP system used by the Finnish ABB. The SAP work queue for the workshop includes all
activities requiring attention from the workers. It has been divided into four parts according to the
different tasks performed at the workshop: production orders, service orders, inspection lots, and
notifications tasks. Production orders include the orders to produce exchange units and to download
software. Service orders indicate repairs. Inspection lots are notifications of received defective
materials requiring inspection by the workers. Finally, notification tasks include various random tasks
requiring attention, from warranty inspections to analyzing drive units as requested by the Pitäjänmäki
factory.

A foreman will inspect the task and decides which worker has the abilities and time to perform the task
based on the foreman’s knowledge and a look on the personal work queues of the workers. The foreman
will manually designate the task to a single worker, at which point it becomes visible in the worker’s
personal work queue and he or she can begin performing the task. After the task has been completed,
the worker will mark it as such in the SAP. Workers often have more than one task in the making,
especially if these tasks include price estimation repairs that require waiting periods before the work
can advance.

These tasks have so-called “routings” or “task list groups” that include planned hours, or the time the
task is estimated to require to be completed. These hours may not be accurate, but often offer a rough
estimate of the time required. Production orders have routings and service orders task list groups. The
difference is caused by the fact that production orders and service orders are handled in different SAP
modules. Notification tasks and inspection lots are handled in another module still, and have no planned
hours included. Different production and service tasks have predetermined lead times promised to the
customer, often quite long in order to ensure that the workshop has time to perform the tasks.
The foremen have visibility to the activities performed by the workers at all times and thus control the workshop by using that information to designate work assignments. However, besides the information that the foremen personally hold, there are no calculations nor information of the capacity of the workshop, and other departments within ABB do not know whether the workshop is busy or not without inquiring the foremen. The workshop does not employ production planners.

Besides this work queue transaction, there are few Excel spreadsheets in place to ease the operations of the workshop. However, these Excels are mainly utilized by the workers in order to keep track of more extensive repair projects or to reserve a slot for testing the units they operate on. They do not offer insight into the capacity situation of the workshop as a whole.

Process charts for the operations performed at the workshop here can be found in appendix V.

![Figure 13: The work queue transaction of SAP presently in use at the workshop, a screenshot 27.5.2016](image)

5.3 Challenges of the workshop operations

Based on the research into the study topic, five of the major challenges facing the workshop capacity management at the moment were identified. These five challenges constitute the most problematic areas
of capacity planning presently. These issues were brought up in interviews of different departments within ABB. The five issues mentioned most often were:

- No knowledge of the theoretical maximum capacity of the workshop
  - The management does not know whether resources are employed efficiently and whether the operation improvements actually improve the processes, since the overall view of the workshop is nonexistent besides the knowhow of the foremen. It is challenging to communicate situations correctly without the help of actual calculations and numbers.

- No knowledge of the amount of free/reserved capacity besides personal work queues of the workers
  - The foremen have to spend a large amount of time and effort checking the personal work queues and estimating the capacity situation – all the time spent on this is away from other errands. The processes they have to use to decide how to assign tasks are complex and time-consuming.

- No visibility to the workshop workload by the other ABB departments such as customer service or sales
  - Sales, customer service and other relevant departments must call or email the foremen directly every single time they have a question about the capacity, e.g., whether an order can be accepted for a certain time frame. This, once again, burdens the foremen and occupies large amounts of their time.

- All information of the current situation held personally by the foremen, and absence of the foremen causes instant delays and zero visibility to the workload of the workshop
  - With no theoretical calculations of the capacity and no view to the workload available, in case the foremen are unavailable, other departments within ABB have little knowledge of the situation at the workshop. Practically all information concerning workshop operations is possessed only by the foremen and not codified anywhere.
• No view to the future workload
  • Due to the nature of the workshop operations such as repairs, a view to the future is quite lacking. In factory environment a production planner can plan the operations and production for the future, but in workshop environment many of the orders only arrive at the same time they are expected to be performed. This lack of visibility to the future causes issues to the operations planning, since foremen can only “look back” to decide how to assign tasks and allocate resources.

In short, the Kiitoradantie workshop operates on all the drives ABB has manufactured and the tasks performed in the workshop vary from repairing broken units to almost factory-like manufacturing of exchange units. The workers are divided into five different work groups based on their skills: “800 department”, “600 department”, “Upstairs”, “Retrofit/Mega/Cyclo”, and “CCC/software downloading”. These groups are supervised by two foremen, who personally hold most information concerning the workload of the workshop. They utilize the ERP system titled SAP in making the decisions to assign tasks and when answering inquiries from other ABB departments, but the system is labourious to use and does not offer an outlook into the overall situation. Capacity control is quite rudimentary and does not support systematic observation and planning of capacity.
6 Solution to the research problem

This chapter will discuss the solution to the research problem presented in the previous chapter. First a framework applied in the research process will be introduced. The introduction will be followed by chapters focusing on each step of the framework, which together construct the complete solution. The chapter will end with a discussion on how the current operational challenges are affected by the solution presented.

In order to create a logical structure for the research and a concrete solution, a framework of capacity control was created (seen in figure 14). The first “step” of the framework is an overview of the current situation of the workshop, as presented in the introduction to the research problem. Secondly there is a look on the capacity control as a part of the work processes: how would a new capacity control system affect the work processes of the workshop? What would be the most optimal process of controlling capacity? After finding out a suitable process for controlling capacity, one should examine the parameters of the capacity control system. The solution to finding suitable parameters is based on the principles of the Theory of Constraints. Finally one should decide the most suitable technical solution in order to implement the changes. All the decisions made in the previous three steps should lead to a new capacity control system taking notice of all the three aspects of the decision-making process.

The overview of the current situation can be found in the introduction of the research problem in chapter five. In summary, capacity control at the workshop is quite primitive and no calculations of theoretical maximum capacity exist. The foremen personally hold the information of the capacity situation and are the only ones able to communicate it further.
6.1 Process view of capacity control

A major goal of this study is to improve and ease the processes at the workshop. At the moment the largest issues concerning the processes are not actually bad practices but the difficulties workers face when using a complicated IT system that does not enable systematical view on the whole workshop, but relies on the personal memory of the person using it. Capacity checks are part of other processes being executed, but they cannot be done automatically or with the help of the IT system. This is what the suggested solution to the case seeks to change.

The persons responsible for controlling the capacity are still the foremen. It was not seen necessary to hire a production planner for now. The capacity is checked and discussed in many situations daily: as a response to customer enquiries, when deciding who to assign a task to, and when deciding whether to transfer a worker from one group to another temporarily. These operations are necessary, yet needlessly complicated. By creating one view that could offer insight into the overall situation of the workshop, not just the work queue of one worker, the processes listed above could become much quicker and easier to perform. In short, the system does not transform the processes themselves, simply
improves them by facilitating an easy way to observe and plan workload at the workshop. This also frees more time for the foremen to focus on other tasks.

After considering the current situation and potential improvements, it was decided in a meeting between the foremen and management on 25.4.2016 that the capacity control system is not required to affect ATP or the lead times of different tasks at the moment. The objective of this project was decided to be to create an outlook on the current situation for the use of the foremen, i.e., a view that does not exist yet. Further complicating the system by enabling lead time confirmation and changes was seen as unnecessary at the moment. It was decided that these changes could potentially be implemented once the system is proven to function correctly and iterated into a view that corresponds to the reality of the workshop. Naturally, the most optimal future state would be one where the actual capacity situation at the workshop would dictate the lead times of each project or customer order. The potential to expand the system to affect ATP and lead times in the future still remains.

6.2 Parameters of the system

Next step is the one of process parameters. In order to calculate a theoretical maximum capacity, one should decide which parameters to employ. This decision affects all others and creates the logic on which the capacity control system is built on, so it is of great importance and requires a thorough discussion. For the purposes of this study, the theory of constraints (TOC) was chosen as the underlying method of finding the solution to the question of which parameters to observe and control.

As the name of the ideology implies, the concept of a constraint is central to TOC. Constraint can be defined as “any element or factor that prevents a system from achieving a higher level of performance with respect to its goal” (Blackstone and Cox, 2004). These constraints cause so-called bottlenecks in the production processes, effectively restraining the process from continuing as smoothly as it would without the constraint. TOC suggests that in order to best control capacity, one should investigate its constraints and plan the work processes around these constraints.

A major challenge of the capacity planning at a service workshop has to do with the nature of the work. Unlike a production line of a factory, industrial service workshop deals with multiple different product and service types, e.g., from repairing circuit boards to producing exchange drive units. The amount of work performed cannot be planned beforehand for the most part, since repairs constitute a major portion
of the tasks at the workshop. Due to the fact that units arrive for repair only once they break, at times the workshop may be overloaded with units, and at times there can be barely any. In case the maintenance of drive units will be more focused on preventive actions in the future, this issue will lose some of its importance, but realistically there will always be unexpected breakdowns of units.

This uncertainty leads to an issue concerning the bottleneck theory, which relies on the concept of a process constraint. In this case, interviews with the foremen and workers indicate that due to a myriad of differing services and unexpected workload situations, the process bottleneck varies nearly daily. The only constant figures consist of the amount of workers, their personal know-how and their weekly working hours. These are the factors that the foremen consider while assigning tasks to workers and while communicating the amount of available capacity to other departments within ABB.

Due to this, one might argue that the bottleneck of this case consists of the one crucial resource every workshop has: labour. Wernerfelt (1984) has argued that the resources a company possesses may actually be the cause of their success or downfall. He suggests that unique resources may give advantage over other companies and specifically references labour as a potential resource for competitive advantage. In this case, this approach seems especially fitting. The amount of workers present on each day determines how much work can be performed. There are nearly always enough work stations, but if one worker gets sick, the whole capacity situation at the workshop transforms and delays become inevitable, more so than in a production line of a factory. Maintenance and repair of drive units is labour-intensive work with very little automation involved. Workers do have instructions to follow while repairing units, but in the end, the skills of the worker determine how quickly the root cause of a fault can be found and fixed. Thus for an industrial service workshop to break its constraints, the focus should be on the amount and skills of the labour.

The concept of Available-to-Promise (ATP) at the workshop functions on the same basis. Through ATP one can provide a response to customer order requests based on resource availability (Simchi-Levi et al., 2004). As foremen communicate the capacity situation to other ABB departments and discuss the ability of the workshop to accept new tasks, they do it in terms of the most important resource present, labour. The amount of skilled workers has the largest impact on available capacity of the workshop, and thus labour can be seen as the constraining resource of the workshop.
The next step is deciding the units whose capacity to observe. In this case, considering that labour is the constraint, the team distribution presented in the introduction of the research problem forms the most logical system to control. Different teams have different knowhow, thus creating five groups that can be viewed as having their own capacity and each having their own group of skilled labour: “800 department”, “600 department”, “Upstairs”, “Retrofit/Mega/Cyclo”, and “CCC/software downloading”. Together these five groups form the total capacity of the workshop. However, the possibility of moving workers from one group to another or momentarily removing a person from a group’s capacity (due to e.g., sick leave or training) should be included in the system. This is especially needed due to the inclusion the fifth group, “CCC/software downloading”. This group does not have a single dedicated worker, but operates as a rotating shift between all workers at the workshop. Thus the possibility of transferring workers from one group to another is absolutely necessary.

The last parameter to consider is that of time. It is clear that all tasks vary in time, but approximations can be made based on average times different tasks require. This information is included in routings or task list groups, as discussed in the introduction of the case. These give an estimate that can be used in the first iteration of the capacity control system. Once the system has been established and proven to function correctly, it is possible to expand the amount of routings or task list groups and focus on making them as realistic as possible.

A more complex issue is that of the so-called price estimation repairs. In these cases, approximately 50% of the work is performed as the unit arrives for repair, but 50% of the work can only be performed after the client has approved of the repairing. Thus it is unrealistic that the capacity is reserved for the whole work amount straight away as the unit arrives. In order to solve this problem, a distinctive time estimation was established for the price estimation repairs. In their case, 50% of the work is addressed to the week during which the unit arrives. The remaining work will only reserve capacity once the customer has sent approval for the repairing. Another option suggested was that price estimation repairs would still be divided into two distinct workloads, but the actual repairing would be allotted straight away into the future workload after the average time it takes for a repair to be approved. Thus the impact of price estimation repairs in the workload would be visible to the viewer instantly.

Notification tasks and inspection lots have no planned hours allocated to them, which is an issue to be noted. Since the capacity control system is based on the time each task takes, these tasks should also
have approximations of time required. For the purposes of this study, the foremen estimated approximate time requirements for tasks in these groups.

The five skilled labour groups, the estimated planned hours allocated to each task, and the working hours of the workers constitute the total capacity of the workshop to be observed and controlled.

6.3 Technical execution

Finally one should decide which technical system to utilise and how to implement the decisions made in earlier phases. In this case the choice of ERP by ABB is already limiting further choices, since most of the information of the products, their materials, location, routings/task list groups, etc. is included in the system. However, this lock-in also provides many possibilities. SAP includes a ready-made capacity control transaction that can be modified to suit the needs of the workshop. Other choices discussed included either creating a completely new program solely for the purposes of capacity control at the workshop or purchasing a ready-made program from an outside consultant. Creating a new program was not seen as practical due to the high costs and risks involved in creating a new program. Purchasing a system outside the company was seen as possible, but considering that SAP already has a module dedicated to capacity control, it was seen as unnecessary and costly. SAP was selected as the IT system of choice, with modifications made to suit the case workshop.

The final solution consists of a SAP-based system with the possibility of exporting the results to either Excel or to a Dashboard view presented on a screen e.g., at workshop floor level. This choice of including the possibility of exporting data was made to enable the inclusion of these screens later if needed. The system itself is built upon the ready-made SAP control transaction CM01, which measures the capacity reserved through so-called work centers. Each task has an assigned work center, which tells the user where the task is being performed within ABB. In this case five new work centers were created to replace the old one, titled TPE, which used to include all the workshop tasks. The amount of workers in a work center is an initial assumption and can be changed within the system in order to best utilize the labour. The amount of workers at each work center is recorded on a table at SAP that the foremen can change as needed. The new work centers are titled:

- Dsw1: 800/880 department, 5 workers
- Dsw2: 600 department, 3 workers
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- Dsw3: 800/550 small frames work center, 3 workers
- Dsw4: retrofit/mega/cyclo work center, 3 workers
- Dsw5: software/ccc work center, 1 worker

These work centers include tasks from the four different work queues: service orders, production orders, inspection lots and notification tasks. These tasks are attached to different work centers through their routing or task list group. Service and Production orders constitute the majority of the tasks at the workshop. Production orders have routings that include the information of the time the task is supposed to take and thus the capacity the task reserves. These existing routings were allocated to the new work centers as thus:

- Dsw1: 1fpstpe3, 1fpstpe4, 1fpstpe5
- Dsw2: 1fpstpe
- Dsw3: 1fpstpe2
- Dsw4: 1fpsret
- Dsw5: 1fpsccc, 1fpssoft, 1fpsval

Some work centers such as dsw1 include more than one routing, whereas others simply have one. Having more routings indicates the possibility of performing tasks that have different planned hours and thus reserve different amounts of capacity of the work center. More routings can be created later on.

Service orders are handled at a different SAP module than service orders and thus have no routings but task list groups. These task list groups include the information of the planned hours of the tasks. At the time this thesis was written, there were 1438 different codes that could be used to indicate a production order of some type. Discussions with the foremen indicated that most of these codes were outdated and not in use anymore. After going through them all, a foreman concluded that 183 of these codes were still relevant, while 1255 could be deleted. New task list groups were created for these existing codes, based on which work center they fit into and how many hours the task types require to be fulfilled. The new task list groups created were (also seen in appendix III with the corresponding old codes):
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- Dsw1-3
- Dsw1-4
- Dsw1-8
- Dsw2-3
- Dsw2.4
- Dsw2-8
- Dsw3-2
- Dsw3-3
- Dsw4-16
- Dsw4-20
- Dsw4-24
- Dsw5-1

The first part of the task list group name indicates the work center it is allocated to, and the following number the hours it should take for a task of this task list group to be finished. Since the work centers operate on different drive types and projects, the hours vary a great deal between the work centers.

Finally the notification tasks and inspection lots remain to be discussed. While simply counting the amount of tasks fulfilled during the time period 8.6.2015-4.12.2016, 21% were either inspection lots or notification tasks. However, one must take into account the fact that these tasks require significantly less time than the other task types performed at the workshop. After factoring in the time requirements (e.g., applying average times for service order: 8 hours, production orders: 4 hours, notification tasks: 1 hour, and inspection lots: 0.5 hours), they actually consist only 3% of the workshop tasks during the observed time period. Thus these tasks were deemed as less important and a large project of creating new time planning system for them was abandoned. These tasks are not, however, completely discarded. They can be given an estimate of time (updated within a table in SAP) that can be connected to a work center through a worker the task is assigned to. Since all workers are connected to the work center they currently work on, all their personal tasks are also connected to the same work center. This way notification tasks and inspection lots are also included in the capacity calculations.

The choices presented above constitute the underlying logic of the system. Once the capacity calculations have been correctly concluded, one should also address the visualization of the system. In
order to apply the data collected, it should be presented in an easily understandable form. In this case, an Excel spreadsheet or a Dashboard screen view suffice to offer a clear view of the capacity situation at the workshop. The foremen wished for the visualization to be as simple as possible: simply a column chart with different work centers displayed as one column each. This column should include the information of how much of the week’s capacity has already been reserved for each work center. Besides these work center columns, there should be one column indicating the amount of price estimation service orders awaiting the customer approval. 50% of the planned hours of these orders have already been consumed, but once the customer service informs the foremen that the repair has been approved, they manually change status of the order into “approved”. After this the remaining capacity reserved transfers from this backlog column to the appropriate work center. The backlog simply illustrates how much work is accumulating due to the price estimation repairs. Another option is one of instantly allotting the repair work into future, reserving capacity like any other task. In this case the repair would be allotted into a week after the average waiting time for customer approvals. In this case, the backlog bar visible in the visualization presented in this thesis would simply not exist. Other attributes of the system’s visualization would remain the same. In both options, colour-coding

Figure 15: Visualization of the capacity control system’s potential appearance; values displayed are arbitrary and chosen for illustrative purposes
should indicate whether a capacity is reserved due to service orders, production orders, notification tasks or inspection lots. Since service orders are direct customer service, whereas production orders may also be MTS products, it is important to be able to prioritize customer orders before inventory products. This is made possible by colour coding the tasks reserving capacity of each work center. The final view of the capacity is also based on weeks since the foremen preferred this instead of a daily view.

Due to the time limitation of writing this thesis, the whole project cannot be completed within its time frame. The changes presented here should require approximately a week for a SAP consultant to realise, as estimated by a consultant of Aplia SAP Consulting on 9.6.2016. However, they can only be first introduced to SAP in the autumn of 2016 when the next ABB SAP release occurs. Naturally after the initial version has been presented, the possibility to add more functionalities to the system remains. One can add more routings or task list groups, more product types to observe, and more intricate processes to follow. Incremental changes can be added based on actual data collected in order to improve the accuracy of the system. However, his study focuses on creating the underlying logic of the system that can be extended later.

6.4 Effects of the solution on the operational challenges

This chapter discusses how the solution presented above will affect the current operations of the case workshop. Specific focus is put on the five challenges of the operations presented before, and how the solution has changed the workshop in regard to them.

The five major challenges concerning the workshop operations were introduced as following:

1. No knowledge of the theoretical maximum capacity of the workshop
2. No knowledge of the amount of free/reserved capacity besides personal work queues of the workers
3. No visibility to the workshop workload by the other ABB departments such as customer service or sales
4. All information of the current situation held personally by the foremen, and absence of the foremen causes instant delays and zero visibility to the workload of the workshop
5. No view to the future workload

The first issue is central due to the fact that without any capacity calculations, it is nearly impossible to communicate to either management or other ABB departments how the workshop is doing. There is no extensive data available to discuss whether work processes are improving as they are being developed further, or whether the workshop is operating efficiently and employing a right amount of people. Until now, these issues have been estimated instead of calculated with actual data. Creating system that describes the state of the system enables users to control the system better than with guesswork. With capacity calculations made visible, larger projects and their timetables can be discussed more easily, and the management will receive a clearer view on the operations of the workshop. Collecting long-term data on the amount of different tasks performed and seasonal changes in the workload are also enabled by observing capacity systematically.

The second issue, or that of the knowledge of the amount of free/reserved capacity, is important for the day-to-day operations of the workshop. One can communicate how much more work can be accepted and how much time has been spent on each different task type once the capacity situation is visible. Before implementing the system, every worker’s personal work queue should have been checked and assessed in order to comprehend a complete picture of the workload at the workshop. The new system creates a simple view that conveys whether a group of workers is busy or not, whether there is need to transfer workers from one group to another temporarily, and whether new tasks can be accepted for a specific week. This eases the foremen’s personal work with simpler visualization of the system that used to require checking multiple screens and operations within SAP. Having a clear view on which kind of tasks are being performed also enables prioritizing them. Considering that production orders are often MTS based whereas service orders are direct customer service, it might be important to be able to separate these types of tasks from each other easily and transfer workers into working with the service orders instead of production orders.

Thirdly there is the issue of workload visibility to other ABB departments. Departments such as customer service often wish to reach the foremen in order to enquire about a customer order or to discover whether a new project can be accepted. Persons interviewed for this study mentioned that these enquiries often causes frustration since the foremen cannot be reached at all times. By sharing the Excel and/or Dashboard visualization of the system to other ABB departments, these departments could also gain visibility to the workload of the workshop and thus lessen the amount of enquiries made daily.
the very least, the foremen have an improved tool for answering these enquiries quicker and more easily.

The fourth issue of all information being held personally by the foremen is also improved by the system. The fact that a manager of a department holds most information and controls the operations is inevitable and can never be fully erased. However, with the new capacity control system, the visibility to the workshop does not fully disappear if the foremen are absent, as it has until now. Other departments and workers are able to check whether the workshop is busy or not and which kind of tasks are being performed.

Finally there is the problem of predicting workload. As discussed before, it is quite challenging to predict the workload of a service workshop due to the fact that tasks are not performed based on the foremen’s plans, but based on the amount of drive units arriving for repair. This is a fact that is impossible to change without the nature of the business changing fundamentally. However, a factor can be inserted into the capacity control system to slightly shed light to the amount of work to be performed in the future. By inserting a backlog bar of price estimation repairs, the amount of repair tasks awaiting customer approval can be made clearly visible. If the bar becomes very high, it is evident that there will be many service orders in the future, considering that most of the price estimation repair cases will be approved for the repair. This eases the prediction of workload at least slightly and once again eases the foremen’s visibility to the capacity situation of the workshop.

In short, a system exploiting the existing IT system titled SAP is planned as a result of this study. It is based on the skills of the workers and thus operates based on the five worker groups introduced earlier. All tasks are given planned hours that constitute the capacity reservation for the task. The tasks are assigned to a certain work group, enabling an outlook to the overall workload of the workshop once collected into one figure by the system. It can be summarized that the main advantages of the capacity control system are creating better visibility to the workshop’s workload for more people, creating a tool for easing the work of the foremen, and enabling better communication to management and other departments within ABB about different topics at the workshop.
7 Discussion on the case

This chapter will discuss the study and its results. First the role of industrial services and workshops in the future will be speculated, followed by a discussion on how humans as constraints differ from the more traditional process constraints. After this potential next steps for the future concerning capacity control at the workshop will be presented. Finally the evaluation and limitations of this study will be addressed.

7.1 Future views on ABB drives service workshops

This chapter will discuss the future of ABB and the importance service will play in it, and how this development can be viewed to be a part of a larger trend of servitization and the birth of the Internet of Things (IOT). The role of workshops and their importance as part of this development will also be addressed.

ABB has been a frontrunner on industrial service operations for some time, as evidenced by the amount of references to ABB found in the academic literature concerning servitization and predictive maintenance. However, at the moment majority of services offered by Drives and Controls Services still fall in the so-called “rapid response” category. ABB seeks to not only increase the amount of services provided, but also to provide more value-added, complicated services such as retrofits, upgrades, and long-term maintenance contracts. ABB aspires to transfer its position in the market and become a more complete service provider, indicating that ABB would move further right in the Oliva & Kallenberg framework (2003) presented in the literature review. ABB announced in the corporate strategy statement of the annual report that ”we are further enhancing our strong competitive position by expanding our customer value proposition with new engineering and consulting services and software-based services” (ABB Annual Report, 2014). This part of the strategy is one of the “building blocks” of ABB’s Next Level strategy for profitable growth, so it is evident that services play a large role in ABB’s future.
Besides services offering growth, another motivation for ABB to focus on them could be seen in the sustainability focused argument of servitization (Turunen, 2013). She suggested that servitization is a way for companies to prolong the life cycle of their products by offering more maintenance and more complex services and thus lessening the environmental impact of their products. One of ABB’s service portfolio’s four areas is titled life cycle management and focuses on these issues. The focus on increasing the relative importance of services and generating multiple ways to either upgrade or exchange older products instead of simply scrapping them aids ABB in creating an environmentally-conscious brand. ABB also highlights environmental issues in their corporate strategy, stating in a highlighted statement that “we help our customers meet their challenges with minimum environmental impact” (emphasis added)(ABB Annual Report, 2014).

ABB’s servitization can also be viewed in the context of a framework provided by Turunen (2013). She suggested that the trajectory for servitizing by industrial companies is to first simply offer tangible products and then increase the amount of intangible services provided as time goes on. This trajectory was discussed by many interviewees of this study. ABB Drives and Controls Service offers services of all the steps on the framework by Turunen except the last one. The amount of services has increased by time, following her prediction of companies’ servitization trajectory.
ABB’s future in the service industry is also affected by the recent technological advances. Besides the more traditional maintenance services, ABB has introduced a remote control monitoring service in December 2015. This service includes monitoring the operations of the drive while it is in use and collecting data for forecasting the maintenance needs of the unit, thus allowing for the principles of condition-based predictive maintenance to be realised. With the globalisation, digitalisation, and urbanization of societies, people are looking for increasingly smarter, more connected products. This larger trend is often titled Internet of Things (Porter & Heppelmann, 2015; Juhanko et al., 2015), or, as ABB has termed it, “Internet of Services, Things, and People” (ABB Annual Report 2015).

Drive units have potential to become part of this phenomenon. They are products often used in multiples in industrial setting, with breakdowns causing huge costs for the companies. By erasing these costs at least partially with predictive maintenance programs the whole maintenance landscape of drive units could be irrevocably transformed, making predictive maintenance the principal maintenance philosophy of drives. In this case, traditional industrial workshop services would lose some of their
importance in the total amount of services offered by the company; if the majority of services at the moment are rapid response services that seek to fix broken units, in the future the collection of the data, analysis of it and communication of the needed operations might compose majority of the services. The importance of workshops performing repairs and installing preventive maintenance kits could decrease in favor of departments analyzing data and developing even better remote control monitoring systems.

However, it is quite unrealistic to expect the unexpected breakdowns to disappear completely. It is highly unlikely that predictive maintenance and IOT could ever fully replace the service offered by workshops. Repairs may lessen in amount, and potentially become easier to perform: the more information the workers have of the actual condition of the unit, the more they can focus on the relevant parts. It is not infeasible that with the remote control monitoring services improving constantly, a service could be created where the unit can recognize itself which part is in need of repair and communicate that to the persons in charge of maintenance. If a unit like this came to the workshop, the root cause would already be discovered and only the physical act of repairing the unit would remain. This would effectively shorten the lead times, lessen the cost of repairs since less time is spent on them, and thus potentially increase customer satisfaction.

On top of that, predictive maintenance measures also require traditional workshop operations even with no breakdowns involved. When the data collected indicates a need for new parts or maintenance, someone must perform these tasks. Naturally in order to keep the unit in best possible condition, one should perform maintenance as recommended by the manufacturer. In case most of the "repair" operations at the workshop would fall into this category, the predictability of the workload might improve. These "repairs" can be scheduled to suit both the customer and the workshop, indicating that the capacity they reserve could be calculated well beforehand. In case more tasks can be predicted further into the future, the capacity control of the workshops as whole becomes easier to manage and more like the capacity control of a production line at a factory.

It must also be considered, though, that these maintenance operations could become operations fully performed where the drive unit is located. In case the design of drives develops into one where a worker can more easily simply replace relevant parts since the unit informs the repairer what to do, there may no longer be a need to send the units into workshops. Thus maintenance operations may offer one of two potential futures for workshop: they might either ease the capacity planning and operations within workshops due to their predictability, or potentially disappear fully from the workshop operations due
to them being performed on location of the drive, not in a centralized workshop. However, this development is likely to take years to come to fruition, since at the moment ABB is still mostly offering rapid response services. Predictive maintenance is a potential future game changer, but is currently only adapted by key customers on a testing basis.

Another factor affecting the workshops’ future is the fact that they do not merely offer repair services. They already produce exchange units, retrofits, and download software, among other tasks. IOT does not directly affect most of these services. Services such as exchange units are production-like operations, very much like those at a production line of a factory. Even if IOT becomes the principal method of controlling drives, it remains a fact that not every customer will wish to instantly invest in expensive, new technology. For many customers, the “bare bones” approach of drives simply controlling their machines and being exchanged once they break down is enough. It must be remembered that drives often support the core business of the customers instead of being the focus of it. Retrofit kits and exchange units may still retain their popularity in the years to come, even if they might begin to include features of predictive maintenance and data collection.

Software downloading is likely to either maintain its importance or grow even more important. The more the importance of data grows in the operation of drive units, the more focus will be on software. One potential route for the workshops to create a new “purpose to exist” would be to position themselves as places where updates of drives can take place. Even if the faulty parts can be simply replaced in the location the drive is being used at, ABB will probably be reluctant to give out software outside the company due to security concerns. It was mentioned in many interviews that currently many of the local service operators of ABB are subcontractors, and thus releasing the software to them would be releasing the software outside the company. In case the software is what differentiates the product and gives it competitive edge over competitors, safeguarding the smart software would be vital. In this scenario, if a unit was in need of an upgrade or updating of a software, it should be sent to the workshop. This would render workshops relevant in the future scenario where some of the traditional workshop operations disappeared from them.

As a whole, IOT may either increase or decrease the overall importance of workshops. On one hand, with services growing in importance for the whole company, workshops become increasingly central to the core competence of ABB. Units may also last longer and be easier to repair with scheduled maintenance than before, leading into easier control of workshop and more orders. On the other hand, the relative importance of collecting and analyzing data might increase instead of direct repairs, and
potential new drive unit designs may ease the maintenance of units on location and decrease the need for shipping them to workshops. However, one fact is clear: The more business focus is placed on services, the more regulated they must become in order to maintain a high level of service quality and customer satisfaction. A workshop whose capacity control is sophisticated can more easily communicate availability to the customers and offer more flexible lead times for the projects and thus increase customer satisfaction. If the services increase in importance, all processes concerning them increase in importance, too, and become more central in creating competitive advantage for the company. Thus one should not disregard the importance of controlling and managing the workshop operations currently and in the future.

7.2 Humans as process constraints

Humans as constraints present a very different view than a workstation as a constraint. While workstation constraint can be broken by simply adding more people working there or adding a second workstation for the same operation, humans are not as simple. Adding to the fact that the constraint is not simply the amount of the workers but also the differences in their skills, one must observe the situation quite differently.

On one hand, humans are a complicated constraint: every person has slightly different skills, different speed of working and different routines. In complicated, skill-intensive maintenance and repair work the work processes are hard to standardize fully. On the other hand, human constraint can be broken not only by employing more people (analogous to adding a new workstations or adding workers to the old workstations) but also by training the existing workers. The more they learn, the more they can be exchanged between departments in situations where more labour is required in one department than another. The skills of the workers also increase during their careers, which can be decades long. Replacing a worker that has worked at the workshop for 40 years with one that has never done any maintenance work is not the same as replacing an old machine with a new one. On the contrary, in this case the “new machine” does not add speed or efficiency but slows the processes down.

Fully codifying this complexity must be considered carefully. Building into the system the knowledge of all the different skills of a certain person is difficult and the effort may outweigh the benefits. The workers are encouraged to constantly learn more and their skill set evolves constantly. It is also impossible to codify every single piece of knowledge and skills a worker possesses, since a lot of them
may be in the form of tacit knowledge. Thus in this study a decision was made to focus simply on the product lines each worker is able to operate on, and create groups that can operate on a certain product line. The responsibility of knowing how to transfer workers from one group to another based on their skills still falls to the foremen. The capacity control solution presented in this study does not fully automatize the management processes of the workshop, but simply aids in performing them.

However, the concept of humans as process constraint may be changing in the future. As discussed earlier, there is a great change happening at the moment: technological equipment is becoming smarter and more connected, and it is possible that drive units will apply more predictive maintenance techniques in the future. As speculated in the previous chapter, this might transform the workshop operations and maintenance. On one hand, more modular, smart drive units could enable easier repairing and possibility to repair the units in the location they are used in. Most major problems would arise in case the predictive maintenance system broke down or distributed false information. These issues would probably not be solved by the workshop, but by the people controlling the IT system. In this case, workshops would be left mostly with repairs of older units and other tasks they currently perform, effectively remaining in a similar situation they are now. The human constraint would remain similar to the current state.

On the other hand, in case the drive unit actually breaks down despite predictive maintenance and smart IT systems, the skills of the workshop workers become even more essential. Finding an unexpected fault requires expertise and intimate knowledge of the unit for a system that should mostly keep itself up and running. Workers would need to specialize into certain type of products even more than they currently do. The skills required by the workers would be even more diverse and cover both repairing older products and understanding a complete new type of units and their faults. In this case, the human constraint would be heightened.

Both of the scenarios described above would either heighten or keep the human constraint similar to what it is currently. However, there is a third option: the option of drive units becoming increasingly similar to each other in terms of design and simplifying due to modular design of the products. Currently the workers at a workshop are divided into different groups based on their skills, with each group being able to perform tasks on a certain type or product line of a drive unit. In case the modular design of drives became commonplace and the older product lines disappeared completely (which is to be expected at some point), these group divisions might disappear. In case all the products had similar designs and the smart aspects of the drive could locate the fault into a specific part of the unit, repairing
them might become easy enough to enable all workers to repair all product types. In this case the central issue discussed in this study, differing skills of the workers at the case workshop, would diminish into nothing. The capacity control based on the five different groups would cease to be relevant, since all the workers could be combined into one group to control simultaneously. Humans would no longer be the major constraint of the workshop. In this case, a new study researching the new constraint would be required. As per the logic of the theory of constraints, once one constraint has been dissolved, the focus should be on finding the next one in order to make the process studied as effective as possible. However, the development presented in this paragraph is relatively far-fetched and would come into existence years and years from now. For now, humans remain the major constraint of the operations. A new look into the situation should be necessary only once the drive business and maintenance environment has radically transformed into something else.

Humans constitute a unique constraint in terms of the theory of constraints: they may be trained and they are each unique. It is impossible to ever fully codify all pieces of tacit knowledge a person holds into an IT system. However, whether humans remain a process constraint in the future is under debate. Due to the radical changes expected in the drive unit business, humans and their skills might even become even more central to the processes due to them solving only the complicated cases IT systems cannot. Another option is that the future drive units might become so smart that humans would not need much training in order to repair them, rendering the current skills-based group division irrelevant. It is vital to observe the development of the technology with these scenarios in mind, and ensure that the workshops operate in a way that supports the ABB strategy.

7.3 Next steps on the topic

This chapter discusses what could follow the study presented here. First there will be a suggestion for the company concerning the next steps they could take. Secondly, there will be a short discussion on the potential academic future research topics based on the findings of this study.

This study can be viewed as the starting point of a capacity control project within the workshop. A rough plan can be formed based on this study in order to continue the improvement of the capacity control at the workshop. Once the system has been created, the following steps could be taken:
1. Iterate the system to its perfection – at the moment there are relatively few routings and task list groups, even though e.g., different repairs at a same team probably require different planned hours. Thus one should

1. Collect data on the planned hours vs. actual hours required by each task. This data collection should take at least a few months, potentially a year in order to get the most accurate results with as little random variation as possible.

2. Compare the data; are there large variations? Are these variations unique cases, or does e.g., a certain frame size always require more or less time to operate on than others do? Find out what connects the tasks that vary from the planned hours.

3. Create new routings or task list groups for these tasks.

Once the planned hours start corresponding to the reality, the need for communication between different departments is lessened and the foremen’s time won’t be tied to phone or email as much as it has been. Since other departments can trust the amount of free capacity visible in the system, they may not need to ask about the possibility of accepting new orders the way they do at the moment. They can simply check the situation themselves and decide whether to accept an order or not.

2. Focus on the lead time confirmation. Until now, lead time has been constant. After the capacity view has been iterated as close to reality as possible, one can start using capacity checks as basis for confirming orders. Since this is probably a larger project, one should assign at least 3-6 months to realise it.

1. Benchmark other ABB departments, such as those in the Pitäjänmäki factory, who use e.g., testing as their constraint and guide all production through a check with testing capacity (a system created for former Industrial Cabinet Drives). Since this system should also be SAP-based in order to function well with the capacity control system, benchmarking within ABB will most probably be the best way to proceed with the project.

2. Find out what changes are needed to implement this system to the workshop environment with a SAP consultant. It is probable that in this phase the issue of connection to BOL and other systems outside SAP become relevant, so it is important to also include interviews and research into these issues.
3- Implement the desired changes.
4- Start out by testing system only to few order types at once. One could start by including non-customer specific MTS orders such as MTS exchange units, so customers won’t suffer from potential mistakes in the beginning.
5- Broaden the scope in case the results are positive.

The most central points of the future are system iteration and order confirmation. The first one is necessary in order to make the system correctly portray the situation at the workshop. The second step is optional and omitting it will not affect the system presented in this study. However, it is a way to improve the system and customer satisfaction by potentially shortening the lead times and working not on estimations, but on actual numbers given by the system. Thus it is advisable to implement the second step, too.

Academically more research could be made into the constraint of this study. Is it common for an industrial service operation to be constrained by the workers, or was this simply a unique situation? How big a role do the skills of the workers vs the amount of the workers play? Is there a fundamental difference with having a constraint that is effectively a resource constraint instead of a process constraint, and should it affect how to manage and “break” the constraint in order to improve the operations? By widening the sample into multiple industrial service workshops in different industries, one could gain a more complete understanding on how the resource constraint of labour affects industrial service operations.

7.4 Evaluation of the study

This chapter will evaluate the quality of the research and the study presented. First a more academic viewpoint will be applied, followed by a discussion on how well the study answered the needs of the company.

In the beginning of the study, the research question and its sub-questions were formulated as following:

1. How could the capacity of drives service workshop processes be managed more efficiently?
   1A. Which resources should be monitored in order to make capacity control more efficient for each process within the workshop?
1B. What kind of changes in the use of ERP software would be required for the case company in order to realize the improvements in capacity control?

Considering that the research resulted in a system that creates better visibility to the workshop’s workload for more people, eases the work of the foremen and operates as a platform for better communication to management and other departments within ABB, one could argue that the first research question was answered. This study offered a solution to how to manage workshop processes more efficiently through better capacity control. The two sub-questions concerning resources to monitor and changes required in the ERP system were also answered in chapter six while presenting the solution in more detail.

This study was conducted within the given time frame of approximately six months. A limited time frame is a necessary part of a master’s thesis, but also imposes limitations on the scope of the study. Had the time frame been longer, there could have been a more thorough benchmarking to other solutions in similar workshops around the world, whether they be owned by ABB or some other company with a similar business structure. A comparison with the solutions foreign industrial drive service workshops have chosen to manage their capacity could have given more potential solutions to the research questions. However, this study limited the benchmarking to Finnish ABB and more specifically the industrial drive operations within the company. This limitation was seen as necessary and most logical in order to conduct the study on time.

Another limitation is the amount and nature of interviews conducted. The most important interviews on the topic naturally include those conducted with the workers and foremen of the workshop, since they have the most realistic understanding of the present situation. Due to this fact, there were multiple interviews with them. However, the less central operations in regard to the study topic, namely customer service, warehouse operations, and so on, were not so thoroughly interviewed. One interview was conducted for each operation. This may have caused misunderstandings on the situation, since the interviewee’s personal beliefs and ideas may affect how they discuss issues within the workplace and which issues they see as important. However, since these interviews were conducted mainly to form a better understanding of the industrial drives business, the amount of interviews is not necessarily a factor that has greatly distorted the actual results of the study.

The interviews were also mostly based on loosely structured conversation around the interviewees’ expertise, which meant that different interviews had different focuses and may have omitted factors
that were vital and brought up in other interviews from some other angle. One can see two sides to this issue. On one hand, the information derived from the interviews is less easily comparable together and less structured this way. On the other hand, this method allowed the interviewee to give most information on things they knew best, instead of simply trying to answer questions about matters they had no knowledge of.

The more theoretical side of limitations can be understood as the issue of applying processes formed for industrial production into industrial service operations. TOC mainly aims to improve the production process and focuses on the most effective way of exploiting different parts of a repetitive process. However, this study was conducted in a service operations environment. Within a workshop, a production planner has less options for foretelling the future workload of the workshop, since the products are simply sent to the workshop and repaired after they have broken down in a relatively random pattern. This makes it difficult to form long-term plans for work distribution. Another challenging issue is the fact that the workshop performs a wide variety of different tasks, from repairing to producing exchange units. The uneven distribution of work and multiple processes changing daily within one work group make it nearly impossible to find a bottleneck within operations, since the bottleneck of Monday may not be the bottleneck of Tuesday anymore. However, by applying the resource-based view of the company, one can conclude that the workers are the most important factor of capacity within the workshop, and thus apply the bottleneck analogy to the workers. Some readers may find this to be a bit of a stretch and thus I am including this in the limitations of the study. However, I stand by my interpretation of the literature on the subject and claim that this analogy is a logical and an applicable one.

Another viewpoint to evaluate this study is to discuss whether it succeeded in answering the needs of the company. In the beginning, the case company expressed its wishes regarding this study, which can be found in chapter one. The most central question posed was that of the resource management: which resource to observe in order to find out the capacity of the workshop? A list of desired outcomes of the study were presented as following (assessment following each point):

- Discovering order types and tasks to be observed in order to create sufficient understanding of the current workload
  - This was answered in the study: tasks included in the system were all performed by the workshop, with focus on service and production orders.
• Discovering a system or a tool enabling this observation
  • This was answered in the study: a modification of SAP transaction was discovered to be the most optimal tool for observing and controlling the capacity of the workshop.

• A suggestion of a resource that could be used as the guiding parameter in the system, i.e., a system constraint
  • This was answered in the study: skilled labour was found out to be the process constraint for each of the groups observed, and thus team division based on the skills of the workers was discovered to be the basis on which the capacity system was built on.

• A suggestion on how this tool could aid in confirming orders based on capacity
  • This was not answered in the study: since capacity control affecting lead times was decided to be unnecessary at a meeting on 25.4.2016 between the foremen and management, the research did not delve into this issue. However, a suggestion on how to potentially include the capacity-based confirmation into the system is presented in chapter 8.3.

• A view on which changes would be needed in the IT system in order to implement the changes discussed above
  • This was answered in the study: a specification of the modifications required was presented as a result of a workshop with an IT consultant, and a work order was opened by the company in order to realise the changes. The exact list of changes required can be found in appendix II.

Based on the requirements given by the company and the solutions provided by the study, one can assess that the study did meet the needs of the company well. Only one point was not answered as desired, and in that case the reason was that it was seen as unnecessary at the moment by the company.
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Bottleneck Management in Industrial Service Operations: A Case Study


APPENDIX I

Interviews conducted for the study

<table>
<thead>
<tr>
<th>Position of the person interviewed</th>
<th>Date</th>
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<td>ABB Vantaa</td>
</tr>
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<td>Workshop Supervisor</td>
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APPENDIX II

SAP modifications required in order to realise the capacity control system:

- A table including information about which worker works at which department
- A functionality of being able to transfer one worker from one department to another or deleting them temporarily in case of illness, training, etc.
- A table including estimations of the times it takes for a worker to complete a notification task or an inspection lot task
- Deleting the redundant production order codes
- Creating new work centers and transferring the old routings to them
- Creating new task list groups
- Creating a functionality for the backlog orders or price estimation orders (planner group: QUA); i.e., a functionality where 50% of the capacity is reserved immediately and 50% only once the status has been changed into “approved”
- Ability to export data from SAP to Excel/Dashboard
- Colour coding the columns to indicate whether the task presented are service orders, production orders, notification tasks or inspection lots
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APPENDIX IV

The interview questionnaire used in the study:

Servitization
- ABB Drives on lähtenyt liikkeelle fyysisten tuotteiden tuotteiden liittämisestä.
- Missä nyt ollaan?
  - Millaisia prosesseja sinun työpaikan lisäksi on?
  - Mitä prosesseja on eniten?
  - Osaatko arvioida, kuinka suuren osan kaikista prosesseista nämä prosessit muodostavat?
  - Mitkä ovat vaikeimpia/eniten aikaavieitä? Miksi?
- Miin ollaan matkalla?
  - Minkä prosessien määrän oletat kasvavan tulevaisuudessa/minkä prosessien määrän oletat kasvavan tulevaisuudessa?
  - Millaisia muutoksia prosesseihin on tulossa (jos suunnitelmassa on muutoksia)?

ATP Eli yksittäisistä asiakastilaauksista ja niiden vastaanottamisesta/varmistamisesta.
- Mikä on nykytilanne?
  - Kun asiakas tekee tilauksen/pyynnön, millä perusteella se vahvistetaan?
  - Priorisoidaanko tilauksia?
  - Millaiset toimitusajat luvataan eri prosesseille? Pysytäänkö luvattuja toimitusajat?
  - Onko tämä muuttumassa tulevaisuudessa? Olisiko sinulla ehdotuksia siitä miten systeemiä voisi muuttaa?

TOC
- Eli yksittäisten tilauksen/ prosessien ongelmakohtien tunnistamisesta.
  - Vaihdeetko tietyn prosessiyön käytännön/päivitys tulevat aikana?
  - Millaisia ongelmia useimmiten on tässä prosessissä?
  - (Millaisia pullonkaulojen tähän hetkelle) Missä kohtaa joudutaan odottelemaan?
  - Miksi kyseinen kohta on pullonkaula?
  - Miten näitä pullonkauloja voisi poistaa/hallita? Onko prosessin tulossa muutoksia?
APPENDIX V

Process charts for workshop operations
TPE - Repair
workshop

TPL - Return
Handling

TPL - Receiving

TPCS - PartsOnLine/ SAP

TPC - Customer

Price estimate repair service (1/1)