Improvement of material supply systems

A case study in a Swedish pharmaceutical company executed on a research and development plant

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Abstract

Material supply systems have for a long time been regarded as an important function with strong potential to increase the performance of companies in different industries. Consequently, substantial research has been conducted in the field. However, in the pharmaceutical industry within research and development plants, material supply systems have historically not been a prioritized function. Therefore, there is a research gap regarding material supply systems in that peculiar context. This study aims to fill that gap by investigating how a material supply system could be designed and which factors are critical to achieve a cost-efficient service level within a research and development plant in the pharmaceutical industry. To do so, a single case study has been conducted at a Swedish pharmaceutical company’s research and development plant. An abductive approach has been applied to both test if the general design principles developed in other industries and business functions can be applied to this context. Further, context specific factors affecting the material supply system design needed to be identified and investigated to adapt the general design principles to the specific context by generalizing data. The empirical data was collected by utilizing focus groups, interviews, observations and documents. The findings yielded that there is a substantial potential for improvement of material supply systems within the context of this study. The existing decentralized inventory structure at the case company was a particularly vital aspect that hindered the system from operating cost-efficiently in relation to the service level and a centralization is crucial to improve. Further, calibration and a general decrease of safety stocks, order points and order quantities is essential to uphold a consistent service level at a justifiable cost at the case company. The general design principles and formulas retrieved from the theoretical framework was partly applicable in the context of this study but needed some adjustments. Especially the low volume articles with high variety in consumption rate was not suitable to be managed by the existing methods and needed another approach. Further, the context establishes high requirements on system dynamics, it comes with boundaries due to laws regulating the industry, and companies in the context generally need to be better at aligning their design factors to the purpose. The result of this study adds valuable content to the research field and fills the gap for material supply systems in the context of research and development plants in the pharmaceutical industry. Further studies are needed in this field to investigate how articles with low and varying demands can be managed within material supply systems cost-efficiently and with high service levels.

Keywords

Centralization, Inventory structure, Service level, Cost-efficient, Pharmaceutical industry, Safety stock, Order point, Order quantity
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Introduction

1 Introduction

This chapter aims to introduce the study through a background, problem description, purpose, research questions, delimitations and an outline to guide the reader through the remaining chapters.

1.1 Background

A material supply system comprises all activities from reception to shipment of goods which can be broken down to receiving, storing, order picking and shipping (Li et al., 2010). Material supply systems can serve different purposes depending on their design. Apart from supplying goods to a recipient, a common function is to constitute a buffer of goods between supplier and receiver to reduce the lead-time (Li et al., 2016). Material supply systems has been a well explored research discipline for a long time (Nunes et al., 2017). The vehicle industry, with Toyota in the forefront, took the lead by developing the lean principles which have been adopted and adapted by other industries in different business functions (Yin et al., 2017). However, in the pharmaceutical industry, within research and development plants, the research on material supply systems has been lagging compared to other industries and business functions. The superior factor of consideration has been safety, which still is the case. Lately though, the need for accessibility, availability and affordability has nourished the initiation of research within material supply systems in the described context (Nematollahi, 2018).

Material supply systems are needed in all companies where materials are consumed or used as ingoing components. In many industries the material supply systems have gained great attention as an area where cost can be reduced, especially within the manufacturing function which often incurs the highest costs in manufacturing companies (Garza-Reyes et al., 2018). Within the pharmaceutical industry however, manufacturing is not the business function incurring the greatest product related cost, but the research and development function. However, despite the significance of the research and development plants and their material supply systems, the extensive theoretical knowledge developed within manufacturing, has not been transferred and adapted to the context of this study. Hence, the lack of research into material supply systems in the pharmaceutical industry in research and development plants poses a knowledge gap with an interesting potential. Further, the theoretical principles for material supply system design are similar regardless of business function which enables the knowledge to be transferred. The industrial differences however, are evident and need investigation (Gjoka et al., 2017).

The purpose of a material supply system is to provide a range of supplies at a given service level (Jonsson & Mattsson, 2016). In the pharmaceutical industry within research and development plants, there is a wide range of consumable lab supplies that needs to be replenished continually to uphold the scientific experiments on the plant. Scientific experiments in different stages and disciplines of research and development require standard as well as specialized supplies. The nature and frequency of the scientific experiments change continually which affects the frequency of use for the supplies. Hence, the material supply system must handle uncertainty and variety in demand without risking disruption (Gjoka et al., 2017).
In the pharmaceutical industry in research and development plants, disruptions due to shortage of supply are very undesirable. Disruptions cause stops in expensive machinery, perishable chemicals and experiments can be spoiled if delayed, and the scientist’s salaries are high why waiting for supplies is costly. Certainly, in relation to the cost of the lab supplies themselves (ExploreHealthCareers, 2018). Consequently, the cost-efficiency of the material supply system is often neglected due to other priorities. In a large enterprise that conducts extensive research and development however, the material supply system constitutes a considerate resource consuming function which justifies research. For companies in the pharmaceutical industry, research can result in practical guidelines for how to design material supply systems in research and development plants. Research is also needed to enrich the theory for how material supply system design can be adapted to different contexts.

1.2 Problem description

A material supply system can be designed with different embodiments to serve a given purpose. Different physical layouts, technological aids and inventory structures can be combined in countless combinations to find the most cost-efficient solution to maintain a pre-defined service level (Jonsson & Mattsson, 2016). The level of centralization in the material supply system affects the fundamental conditions for the system. Thus, it is of great importance to be considerate when deciding on how many inventory levels and inventory points there should be in the material supply system (Nematollahi et al., 2018). Generally, the inventory handling cost is constituted of the square root of the inventory holding cost, which implies that having a centralized structure with fewer and consequently larger inventories reduces the total handling cost (Eppen, 1979). On the contrary, a centralized inventory structure generally requires longer, hence, more expensive transports (Jonsson & Mattsson, 2016).

In the pharmaceutical industry there are certain aspects and regulations that complicates the context surrounding the material supply system for lab supplies which differentiates from other industries (Nematollahi, 2018). Depending on the type of research that will be conducted when utilizing the supplies and the laboratory environment, there are certain regulations that applies and affects the material supply system. A few examples of practices that apply are Good Manufacturing Practices (GMPs), Good Laboratory Practices (GLPs) and Good Clinical Practices (GCPs) (Benner, 2009). Different research disciplines are subject to different practices and the strictest requires very tedious handling and therefore it would not be cost-efficient to apply it to all disciplines. Consequently, different practices are needed within the plant. Additionally, traceability is of great importance in the pharmaceutical industry, which implies that the supplies must be possible to trace to a source through authorized supply chains (Benner, 2009; Perkel, 2015). The general solution to these problems is that there are usually separate supply channels for the different classifications of experiments to simplify the material handling (Cloatre & Pickersgill, 2014; Perkel, 2015). Separating the channels altogether however, incurs high costs.

Apart from the complexity due to safety regulations in the pharmaceutical industry in research and development plants, the variety and uncertainty in demand is severe and availability requirements are very high (Nematollahi, 2018). This implies that material supply systems in research and development plants in the pharmaceutical industry are subject to context specific factors. Those factors often affect the material supply system
design negatively from a logistical viewpoint. Cost-efficiency and individual viability are factors which generally need to be validated to justify a products existence in a material supply system. In the pharmaceutical industry within research and development plants however, even products which are barely turned over and incur high costs, still need to be provided with a high service level to secure the future research (Jonsson & Mattsson, 2016; Shukran et al., 2017).

There is already existing research on which regulatory requirements and contextual specific conditions within the pharmaceutical industry that need to be met by a material supply system to ensure scientifically proven and secure conditions (Benner, 2009). Further there is a great body of research on how material supply systems should be designed and managed to achieve logistically- and cost-efficient results in general conditions (Jonsson & Mattsson, 2016). However, it appears to be an unexplored research area on how to bridge the gap between the two theoretical areas (Shukran et al., 2017).

1.3 Purpose and research questions

Material supply systems is a crucial function in all companies that utilizes materials as ingoing components or consumables. A material supply system is relying on several design factors which establishes the conditions for cost-efficiency and service level in the system. In this report, cost-efficient is defined as a cost that is economically justifiable based on the provided benefits it entails. Service level is defined as the ability to supply demanded materials within the agreed upon time. In the pharmaceutical industry in research and development plants, the research on material supply systems has been lagging. Hence; the purpose of this study is;

*To investigate how a material supply system for consumable lab supplies can be improved within a research and development plant within the pharmaceutical industry.*

Improve in regard of material supply systems is in this report defined as increasing the efficiency in the relationship between cost and service level. To fulfil the purpose of the thesis, the characteristics of the pharmaceutical industry needs to be investigated further to identify critical factors that are crucial to consider when designing a material supply system. The first research question is formulated for that matter.

1. What factors are critical to achieve a cost-efficient service level in a material supply system for consumable lab supplies within a research and development plant in the pharmaceutical industry?

When the critical factors have been identified, different design options need to be investigated to understand their effect on the cost related to the service level in the system. For this matter, the second research question was formulated.

2. How could a material supply system for consumable lab supplies within a research and development plant be designed to achieve a cost-efficient service level in the pharmaceutical industry?

These research questions will be investigated through a single case study within the Swedish pharmaceutical industry.
1.4 Scope and delimitations

This study investigates the possibilities of adapting and implementing the concepts and theories of material supply systems, mainly developed and utilized in the vehicle industry within manufacturing, to the pharmaceutical industry in research and development plants (Figure 1).

This study will focus on certain factors that are critical to achieve a cost-efficient service level in a material supply system within a research and development plant in the pharmaceutical industry. The factors that will be investigated are: material supply system, design parameters, technical tools, contextual influence and administrative resource consumption. Further, the study aims to generate a design suggestion for how the design parameters, inventory structure, order point, order quantity and safety stock, can be combined and dimensioned to achieve a cost-efficient service level. The design suggestion will be delimited to concern the activities between internal reception of goods at inventories, to delivery of goods to the Point of Use (PoU) (Figure 2).
1.5 Outline

Chapter one introduces the study and motivates why the topic is of interest and justifies why research is needed. The problem that this study will focus on is described, a purpose is formulated to demonstrate the aim and two research questions are established to declare what answers this study will strive to find. Finally, the delimitations narrow down the scope of the study.

The second chapter introduces and describes the theoretical knowledge present in the field of this study. Both associated to general material supply systems and the pharmaceutical industry within research and development plants.

Chapter three describes the methodological approach of this study and motivates the selection of the research instruments and how they have been applied. Also, a discussion of the research quality is conducted.

In chapter four, the findings and analysis are presented. Structured on the research questions, the empirical data is presented and analyzed based on the theory from chapter two, aiming to answer the questions.

In chapter five, the method and findings of the study are discussed. Further, the conclusions drawn from the study are presented as well as its implications.
Theoretical framework

2 Theoretical framework

2.1 Introduction

In the following chapter, the theoretical framework of this study is presented. The chapter is divided into six sections. The first section (material supply systems) introduces the conditions and purpose of a material supply system. The second section (design parameters) describes the fundamental general parameters that a material supply system is based on and their interrelated effects. The third section (technical tools) introduces what kind of technical assistance is available within material supply systems. The fourth section (material supply systems in the pharmaceutical industry) describes the characteristics of the industry and the context that this study will be conducted in and its effect on the material supply system. The fifth section (administrative resource consumption) introduces the administrative resource consumption and how it is affected by the given industry and the calibration of the parameters. The first five sections and their interrelations are illustrated in Figure 3. Finally, the sixth section (concluding theoretical framework) summarizes what theoretical findings will be utilized in this study.

![Figure 3: Illustration of the investigated areas of theory and their interrelationsions.](image)

2.2 Material supply systems

A material supply systems fundamental purpose is to receive material and supply it to the points where it is demanded. The main activities needed to do so can be categorized as receiving, storing, order picking and shipping (Li et al., 2010). Within different industries and business functions, the circumstances and objectives for the systems differ vastly why different characteristics are valued in the material supply systems. However, the underlying mechanisms and fundamental principles for how a material supply system is designed and perform, are similar and possible to adapt to suit all requirements and circumstances posed by different industries and business functions (Li et al., 2010).

The aspects which stipulates the most fundamental condition for the material supply system come from two directions. One is the requirements from the demand side which stipulates the service level, which describes under which circumstances the supply
Theoretical framework

should be delivered towards the customer side, out of the system. From the other side of the system there is a delivery lead-time which describes under which circumstances the supply will be delivered into the system. Between those, often fixed parameters, the work activities in the system occur, aiming to maintain the service level based on the conditions set by the suppliers of the material. Within the boundaries stated above, the material supply system is designed and should aim to perform cost-efficiently (Johansson, 2007; Jonsson & Mattsson, 2016).

2.3 Material supply systems in the pharmaceutical industry

The demand for greater product variation and shorter lead-times have directed companies in different industries to focus their research towards developing the material supply systems to accommodate the market requirements. The aggregated knowledge has been widespread and utilized and adapted to many different industries and business functions, even many that has not been driving the development, have still benefited from the derived knowledge and implemented the theories (Li et al., 2010). Research and development plants within the pharmaceutical industry however, has not benefitted from the development of theories and practices for material supply systems substantially. Therefore, material supply systems are a relatively unexplored research area within that specific context (Shukran et al., 2017).

The reason behind the pharmaceutical industry’s neglect in material supply systems in research and development plants may be because it is considered to stand too far outside the key activities. Further, the circumstances for the materials in the system are regulated by very strict laws which makes the conditions for improvement complex and difficult for professionals from other industries to grasp (Benner, 2009; Nematollahi, 2018). Also, the nature of the consumption is far more unpredictable within research and development compared to manufacturing. Further, the scientific experiments conducted require a wide variety of perishable materials in varying amounts. The researchers consuming the materials that are supplied by the system are incurring high labor costs and utilize expensive machinery why the access to the material historically has been considered a very important aspect of the system and cost has not been considered extensively (ExploreHealthCareers, 2018; Nematollahi, 2018).

The common aspects generally sought after from a material supply system is a high service level provided at the lowest possible cost. Consequently, the efforts within the research discipline has been focused on how to find a perfect balance between the two, and how to maintain the service level at ever decreasing costs. Within the pharmaceutical industry in research and development plants however, the emphasis on availability and met safety regulations is regarded far superior to all other aspects. The cost aspect has therefore lacked emphasis. Lowering the service level in favor of cost is therefore not an attractive option. Reducing cost should instead be achieved by operating more efficient (Benner, 2009). The factors with the greatest importance that differentiate material supply systems in research and development plants in the pharmaceutical industry, from general material supply systems are illustrated in Figure 4.
Theoretical framework

2.4 Design parameters

In this section the design parameters which form the base for material supply systems are introduced and theorized. The parameters are listed in Table 1 together with brief descriptions.

Table 1. Design parameters for material supply systems.

- **Inventory Structure**: The total number of inventory points and the number of inventory levels they are structured under within a material supply system (Jonsson & Mattsson, 2016).
- **Order Point**: The amount of goods in inventory that indicates that a new order should be placed to refill the inventory (Caceres, 2018).
- **Order Quantity**: The quantity of goods that is ordered when the order point is reached to refill the inventory (Astrom, 2001).
- **Dimensioning of Safety Stock**: The amount of goods to keep in inventory in excess of what is expected to be consumed during lead-time to guard from variations in demand (Manakar et al., 2016).

2.4.1 Inventory structure

Centralization is a term used to describe the structural layout of a material supply system. The level of centralization within a material supply system is dependent on the number of inventory levels and the total number of inventory points. The fewer inventory levels and points, the more centralized the material supply system is. The relation between inventory levels and inventory points is illustrated in Figure 2. The level of centralization affects the performance of the material supply system in terms of for example distance to customer, cost of transport, delivery time, economies of scale, amount of non-value adding activities and obsolescence (Jonsson & Mattsson, 2016).
Theoretical framework

The fundamental theory behind the different types of structures is that a centralized system will require a lower inventory holding cost while a decentralized system will incur less transportation cost. The reason for the lower transportation costs is that a higher number of inventory points reduces the delivery area every point must cover and thereby shortens the distance of the transportation (Jonsson & Mattsson, 2016). The holding cost is lower with a centralized structure because the risk of running out of supply is mitigated by consolidating the inventory to fewer inventory points per level in the inventory structure. With a stochastic demand, a centralized safety stock will provide a higher service level than several safety stocks in a decentralized structure with the same total stock level. That is because variations in demand from a greater amount of inventory points will neutralize each other when they are consolidated to one point. A higher demand than expected from one inventory point will be levelled out by a lower demand than expected from another point. The risk of a certain portion of all inventory points having unexpected high demands at the same time, resulting in shortage, is lowered as the total amount of inventory points per supplying inventory increases (Lee & Jeong, 2009). Thus, establishing the optimal inventory structure means finding the perfect balance between transportation cost and inventory holding cost that is associated with the decision on level of centralization (Lee & Jeong, 2009).

The product characteristics and the transport situation also affect which level of centralization is most beneficial in a specific context. High product value in comparison to the transportation cost makes the conditions for a centralized structure fruitful because it results in high inventory holding and obsolescence costs. Those costs are mitigated by utilizing a centralized structure. The nature of the demand affects the conditions as well. Frequent and small orders make the transportation cost greater per delivered product (Jonsson & Mattsson, 2016). Apart from the balance between transportation cost and the inventory holding cost, there are usually more administrative and handling costs associated with a decentralized structure. If the decentralization implies more inventory levels, the goods will have to be loaded and repacked more times. A general increase of inventory points might also require more employees in total. That is because the utility management is more difficult when the demand is varying, small and spread to several locations which usually is the consequence of decentralization. Further, in a centralized structure the inventories are bigger with greater turnover which makes it justifiable to invest in expensive but efficient equipment that can improve the efficiency of the employees in the inventory (Hartman & Dror, 2003).

All the factors above affect the profitability of utilizing either a centralized or decentralized inventory structure. Further, even with a given degree of centralization, the system can be calibrated and managed in countless combinations. A general formula for the optimal structure is therefore not available. However, there are two formulas that can be used for guidance when designing an inventory structure. The first one is concerning the amount of total inventory needed to maintain a given service level depending on number of inventory points. If \( n \) is the number of inventories there used to be within an inventory level and \( m \) is the number of inventories there will be in the future, the total amount of stock needed with a given service level changes as follows (Jonsson & Mattsson, 2016).

**Formula 1:** \( \text{Savings share} = 1 - \sqrt{m}/\sqrt{n} \)
Theoretical framework

The second formula describes the inventory handling cost in relation to size of the inventory where $H = $ handling cost and $N = $ size of inventory. It states that the inventory handling cost grows at a factor as follows (Eppen, 1979).

Formula 2: $H = \sqrt{N}$

2.4.2 Order point

The order point is a given inventory level which indicates that an order needs to be placed to replenish the inventory. The order point should represent the amount of inventory needed to supply the demand during the delivery lead-time. Further it should leave room for variations in demand during delivery lead-time and overall uncertainty. That is done by adding a safety stock which, in practice, is an excess inventory which is never utilized if the demand is completely stable. It is described further in Chapter 2.4.4. The order point can be calculated as follows (Jonsson & Mattsson, 2016):

Formula 3: $Order\ point = Safety\ stock + Demand \times \ Lead\ time$

When the order point is reached, an order is generated. The size of the order should be the pre-decided order quantity, which is introduced in the next Chapter 2.4.3, and the possible shortfall. The shortfall represents the difference between the order point and the actual inventory which may occur if there is a large outtake from the inventory causing the inventory level to drop below the order point (Caceres, 2018). Figure 5 illustrates the inventory level during theoretical period where four orders are generated and received.

Figure 5: Ordering point, adapted from Jonsson & Mattsson (2016, p.311).

2.4.3 Order quantity

The order quantity is the amount of goods to order when the order point is reached to replenish the inventory. Deciding on an order quantity can be done in several ways. A good starting point is to calculate the economic order quantity, the quantity that is the most cost-efficient to order (Alstrøm, 2001). The economic order quantity is derived by finding the order quantity where the ordering costs and the inventory holding costs intersect (Figure 6). This is the order quantity that generates the lowest sum of the inventory holding and ordering costs (Jonsson & Mattsson, 2016). The ordering costs are the costs that are associated with generating a new order and the inventory holding costs are the costs associated with holding the ordered goods in inventory. For
perishable goods, a substantial part of the holding cost is due to inventory being spoiled or turning obsolete (Udayakumar & Geetha, 2017). High order quantities increase the turnover time which is negative for perishable products such as most lab supplies. The term perishable can be further categorized into products that age and have expiration dates such as milk, and products that become irrelevant and obsolete such as cell phones. Lab supplies are subject to both categories (Santhi & Karthikeyan, 2016).

The economic order quantity can be calculated as follows (Jonsson & Mattsson, 2016).

\[ \text{EOQ} = \sqrt{\frac{2 \times D \times O}{I \times V}} \]

The definition of the ingoing variables in the formula is: \( D = \) demand per time unit, \( O = \) order cost per order occasion, \( I = \) inventory holding interest in percentage per time unit and \( V = \) unit value. The order cost per order occasion constitutes for example, administrative order handling cost and material handling costs. The inventory holding interest is a factor placed on the goods to correspond with the inventory holding cost. It is for example the cost of tied up capital, rent for the storage area, insurance, damage and obsolescence (Bedyaeva & Kapitanov, 2015).

Apart from the calculated economic order quantity, there are usually other aspects that influence what the standard order quantity is set to. The supplier might offer discounts for large orders which makes it profitable to order a larger quantity. Perishable products might expire faster than they are demanded and there might be a packing size which does not comply with the economic order quantity. Further, the physical inventory capacity might not be sufficient to absorb the full economic order quantity or in other ways set conditions that affects the possibility of committing to an order quantity. Thus, companies that use the economic order quantity, often adapt it to suit the specific system (San-José et al., 2017; Bedyaeva & Kapitanov, 2015).

2.4.4 Dimensioning of safety stock

The purpose of a safety stock is to absorb variations in demand and delivery performance from suppliers to reduce the risk of running out of supplies (Caceres, 2018). The dimensioning of the safety stock is based on how much risk the company is willing to take of running out supplies in relation to the inventory holding cost. The cost of the safety stock is calculated as in the denominator of Formula 4; inventory holding interest in percentage times unit value (Manatkar et al., 2016).
The theoretical framework

The dimensioning of the safety stock can be calculated with the following formula (Jonsson & Mattsson, 2016).

Formula 5: \( SS = k \times \sigma \)

The definition of the ingoing variables is: \( SS \) = safety stock, \( k \) = a safety factor that is given by the service level that the company has decided on and \( \sigma \) = the standard deviation of the demand during the delivery lead-time. Given that the demand is stochastic and follows a normal distribution (Jonsson & Mattsson, 2016). The resulting amount generated by the formula will then supply the demand during the delivery lead-time with the service level used in the formula. If the service level is 95% it means that there will be a 5% risk of shortage during the lead-time. This implies that the order quantity affects the long-term risk of running out of supplies, as the risk of shortage occurs with a given percentage every time the order point is reached and an order is placed. Thus, the frequency of orders will affect the overall risk of running out. As stated above, a 95% service level results in a 5% risk of running out during a period with one order. However, if the product is ordered twice during the same period the service level during that period will be \( 0.95 \times 0.95 = 0.9025 \), 90.25% with a 9.75% risk of shortage since the product risks to run out twice. The frequency of orders is given by the order quantity. The larger the order quantity is, the smaller the risk is of running out during a given period with a given service level per lead-time (Alstrøm, 2001).

The theory that supports the formula on safety stock calculations can be illustrated graphically (Figure 7). The three lines represents varying demands during the lead-time and how the safety stock absorbs the unusually high demand.

![Figure 7: Illustration of a stochastic demand variation during the lead-time where \( \sigma \) is the standard deviation of the demand during the lead-time. Adapted from Jonsson & Mattsson (2016, p.330).](image)

Safety stock calculations based on stochastic demands usually perform with high accuracy. However, when the lead-time is short and the demand is low it is hard to estimate the standard deviation during the lead-time (Alstrøm, 2001). An alternative method for goods that fulfils those criteria is to manually estimate the safety stock based on experience and historical knowledge of demand. Still, consideration should be focused on the cost of keeping inventory versus the consequences of running out (Jonsson & Mattsson, 2016).
Theoretical framework

Usually goods in material supply systems have different service-levels, depending on what is regarded important, they are therefore segmented. The most common model when segmenting goods in inventories today is the pareto principle. The pareto principle says that out of the products that are kept in inventory, there will be a segment of products, approximately 20% that results in approximately 80% of the turnover. It is therefore reasonable to segment these products and manage their inventory system separately and vice versa (Fichtinger, 2017). A second method to segment products is to use an ABC classification. An ABC classification is a method used to segment products by factors related to their picking, value, demand and shortage characteristics (Li et al., 2016). When allocating safety stocks, the lead-time, variation during lead-time and cost of keeping inventory are three factors that are relatively easy to account for and base an ABC classification on (Fichtinger, 2017; Teunter et al., 2017).

2.5 Technical tools

A material handling system generate, and is dependent on high levels of data which must be stored, categorized and presented through a suitable channel at the right place and time. Normally this activity is supported by some sort of technical assistance. The storing activity is often supported by digital systems which simplifies the tracking by keeping an updated inventory balance. Lately, technical tools have also enhanced the order picking, often with hand held devices which enables fast scanning and mobile, up to date, picking lists (Li et al., 2016).

The technical system can be divided into three layers; presentation, business and data. The presentation layer is the interface between the users and the data in the system. The business layer could be described as the functions within the system which directs the data through algorithms to the presentation layer. Lastly there is a data layer which contains all the raw data that the business layer retrieves its information from before directing it to the presentation layer. The fast technical development has resulted in new possibilities by enhanced availability and accessibility of data. In systems where lean principles have been adopted, the amount of information is often high and frequent flowing, which makes technical solutions extra favorable. Digitalized Kanban is an example that has been applied frequently in organizations (Mo et al., 2013).

2.6 Administrative resource consumption

The main activities of a material supply system can be categorized as receiving, storing, order picking and shipping as illustrated in Figure 8 (Li et al., 2016). They are all activities consuming administrative resources which can be mitigated by physical, visual and technological tools and aids. The extent of assistance from effectivization by technical tools however, is limited by cost of instalment and the characteristics of the products and inventory configurations. Utilizing technical aids to some extent though, have become standard practice in most material supply systems (Liu et al., 2017). Further, the material supply system layout affects the ease and length of transport, complexity and handling of the products. Also, a centralized structure generally enables more technical aids and less handling but longer transports as described in Chapter 2.4.1 (Jonsson & Mattsson, 2016; Hartman & Dror, 2003).

The main challenge companies are facing today within material supply systems are related to inbound system inefficiency (Li et al., 2016). The main activities require
plenty of administrative resources and with wide article assortments there is a lot of complexity in the system which is difficult to standardize, especially when the articles vary in shape, size and value. Out of the main activities, the order picking is the far most resource consuming and incurs 50-75% of the warehousing costs (Liu et al., 2017; Li et al., 2016; Quader & Castillo-Villar, 2018). Common reasons that hinder the material supply system are unnecessarily high inventory levels and inefficient structure and layout, resulting in excessive handling, counting and receiving efforts (Tracey, 1995).

The order quantity, described in Chapter 2.4.3, affects the storing aspect and the receiving aspect in the material supply system. If the order quantity is high, the average inventory level and consequently cost of storing will be high. This is accounted for in Formula 4, if the economic order quantity is utilized. A lower receiving frequency will also decrease the cost of receiving. The frequency of receiving however, is not accounted for in Formula 4. It is a variable that is difficult to measure because it differs between cases. Very small orders resulting in frequent receiving will however make the receiving similar to a reverse order picking, which is known as the most resource consuming activity (Cambell & Joshi, 1991).

![Main activities in a material supply system](image)

**Figure 8:** Main activities in a material supply system.

### 2.7 Concluding theoretical framework

To summarize the chapter, the theoretical concepts and definitions that will be applied and utilized in this study are described. The conditions stipulated for a material supply system’s work activities originates from the delivery lead-times which the materials are delivered into the system with, and the customers expected service level that the material are delivered to (Johansson, 2007; Jonsson & Mattsson, 2016). The work activities in the system can be categorized as receiving, storing, order picking and shipping (Li et al., 2010). The method these activities are executing with, and the layout they are arranged in, has a great effect on the process efficiency. This is an area with high potential because inbound process inefficiency among these activities is considered one of the biggest challenges in material supply systems (Li et al., 2016; Tracey, 1995). Various technical tools can be used to increase the efficiency of the work activities and especially the order picking which is the most resource consuming (Liu et al., 2017; Li et al., 2016; Quader & Castillo-Villar, 2018).

There are four design parameters in a material supply system which are decisive for what costs will be incurred and what service level can be achieved. These have been studied extensively, especially in the context of car manufacturing, and general theoretical concepts have been widely accepted. The inventory structure describes the number and arrangement of inventory points in the system. The fewer inventory points, the more centralized a system is, and vice versa (Jonsson & Mattsson, 2016). A high service level can be achieved using both a centralized and a decentralized structure but a centralized structure generally incurs higher transportation costs and a decentralized
structure incurs higher inventory holding costs, according to Formula 1 (Lee & Jeong, 2009; Jonsson & Mattsson, 2016). Further, a centralized structure generally has larger inventories which has a positive effect on the handling costs in accordance with Formula 2 (Eppen, 1979).

The order point and the safety stock are related to one another as the safety stock is an ingoing component in the order point. The safety stock constitutes a buffer in the inventory to absorb variations in demand. A higher safety stock increases the service level and the inventory holding cost why a trade-off must be conducted based on what the service is worth to the company (Alstrøm, 2001; Caceres, 2018). The safety stock is calculated using Formula 5 (Jonsson & Mattsson, 2016). The order point is calculated using Formula 3 (Jonsson & Mattsson, 2016).

The order quantity is the fourth design parameter and describes the number of articles to order when the order point is reached. The order quantity is decisive for the ordering costs and the inventory holding costs as the ordering costs increases with smaller, hence, more frequent orders. The inventory holding cost increases with bigger orders which consequently stay longer in inventory (San-José et al., 2017; Bedyaeva & Kapitanov, 2015). The economic order quantity represents the lowest total cost and is calculated using Formula 4 (Jonsson & Mattsson, 2016).

In the pharmaceutical industry, in research and development plants, the above described theoretical design principles have not been applied (Shukran et al., 2017). The context of the study has specific factors that differentiate it from the context that the concepts was developed in. These factors are; strict laws, varying and unpredictable demand, perishable materials and high requirements for availability why the general concepts may be inadequate (Benner, 2009; ExploreHealthCareers, 2018; Nematollahi, 2018).
Method and implementation

This chapter introduces and justifies the choice of methodology and the execution of it. It is divided under the topics: research process, research approach, research design, data collection, data analysis and research quality (Figure 9).

Figure 9: Illustration of the topics in the method and implementation chapter.

3.1 Research process

The research process was ongoing between the 15th of January 2018 to the 23rd of April 2018. The study was initiated with a pre-study which stated the direction of the report and established the purpose and research questions. A literature review was initiated in the pre-study and continued throughout the majority of the study to form the theoretical framework and part in theory matching with phenomena investigated in the case study. The case study has been conducted by utilizing the research instruments; interviews, observations, focus groups and documents. The research instruments were not utilized in any particular sequence but mixed throughout the study because the phenomena where usually investigated one at a time by applying all applicable research instruments. The stages and their contents of the research process are illustrated in Figure 10.

Figure 10. The research process of the study.

3.1.1 Pre-study

The aim of the pre-study was to establish the purpose, research questions and directions for the continuation of the study. Initially a wide literature review on material supply
systems was conducted to acquire a base of general knowledge regarding the efficiency of material supply systems in the pharmaceutical industry, which is the unit of analysis of this study. The review was later narrowed down to be more specific towards the pharmaceutical industry within the research and development business function to investigate the associated conditions. In parallel with the narrower segment of the literature review, three convergent interviews of one, to one and a half hour were conducted to discuss the scope, aim and direction of the study with representatives of the case company. The first interview was with the head of the department of facilities management, which is the department responsible for the material supply system at the case company. A global category manager which was the supervisor during this project and responsible for the contract that performs the work activities in the material supply system. The last participant was the contractor’s representative, who is responsible for the contract on the material supply system. The next two convergent interviews had the same participants except the head of the facilities management had been replaced by a technical specialist from the same department. Apart from establishing the purpose and research questions with theoretical backing from the literature review, the convergent interviews resulted in connections to the relevant employees for interviews and locations and activities to observe.

3.1.2 Literature review

The literature review was in the initial phase of the study, focused on defining the scope and research area of the study. This was achieved by first gathering general information regarding material supply systems and then shifting focus towards the pharmaceutical industry in research and development plants to identify the gap in research that this study is aiming to fill. The initial phase of the literature review generated general concepts for designing a material supply system. However, these concepts were not strictly applicable for the pharmaceutical industry in research and development plants. Instead, industry specific conditions were identified with putative effects on the design of the material supply system. The design concepts and influencing industry specific factors were categorized and described in the theoretical framework.

The sources used for this study were mainly academic reports for the key theoretical concepts as it was regarded the most credible and relevant source. The more fundamental and well-established theories on material supply systems have been retrieved from books because those theories are widely accepted and not described in academic reports. The remaining industry and company specific information have been retrieved from webpages. The selection of the literature has been based on, (with decreasing significance), relevance to the topic, type of source, year of publication and number of citations. Most formulas and graphical illustrations describing the well-established and fundamental theoretical concepts was retrieved from one source (Jonsson & Mattsson, 2016), to maintain conformity in terminology and graphical design. However, these fundamental concepts are described in other literature too why the credibility of the results generated by the formulas is not relying on solely one source (Choi, 2014; Thomopoulos, 2015; Trapero et al., 2018).

The search for relevant literature have been conducted through, (with decreasing frequency), Scopus, Primo, Google Scholar and the relevant webpages for industry and company specific information. The key search terms that have been used were initially variations of: material supply system, material handling system, order point, inventory
holding cost, economic order quantity and safety stock. Later the searches were focused on industry specific concepts and more key terms were added to the searches. The later phase of the literature search included, in addition to the previous ones: pharmaceutical industry, research and development and laws and regulations.

3.1.3 Case study

A case study was conducted at AstraZeneca’s research and development plant in Gothenburg. A case study was selected as research strategy and used in this study to collect empirical data with the research instruments: interviews, observations, focus groups and documents. The broad spectra of research instruments were selected to suit the varying nature of the research questions. The first one requiring more qualitative data and the second one, more quantitative. The case study was conducted partly in parallel with the literature study with an extensive time frame to allow for theories and empirical findings to be cross checked and tested vis-a-vis and pave the way forward. The aim of the case study was to study a material supply system in the real life-context selected for the study. The intention was to investigate how phenomena described in theory appear in the specific context of the case company today, or how they could be applied in the future. Further, the case study was conducted to identify new phenomena in their real-life context with purpose to generalize the data to build new theory.

3.2 Research approach

The research approach can be defined as the logic behind the conscious scientific reasoning that supports conclusions (Kovács & Spens, 2005). The relation between theory and empirical findings in this study has followed an abductive approach which is known to be well suited for case studies. An abductive approach implies that a study goes back and forth between theory and empirical findings. Theory can be applied to phenomena in their real-life context to test hypotheses and findings from the case can be generalized to build new theory alternately. An abductive study is often initiated by a real-life observation of a phenomenon effecting the unit of analysis in a way that does not comply with existing theory. The observed phenomena in this study concerned the material supply system which did not comply with the general design principles described in theory (Kovács & Spens, 2005).

Based on the observed phenomena, theory has been examined in the research area of the unit of analysis and adjacent areas to thoroughly investigate possible matches between observations and theory throughout the study. When no theory matching has been possible, intuition based on the observed phenomena has been used to create theory which has been applied to the phenomena in the case company and tested with the research instruments (Graneheim et al., 2017). Further, general theory on the phenomena has been applied and tested in the case study to distinguish which factors affecting the phenomena aware universal and which were bound to the context. Thus, the study has moved back and forth between theory and empirical findings, seeking patterns and evidence of new theory to already existing phenomena (Kovács & Spens, 2005).

The immaturity of the research area and the insufficient theory regarding the unit of analysis and associated phenomena required the study to be explorative in the initial phase. It aimed to identify patterns in data that could be generalized to a wider context (Williamson, 2002). To identify tendencies and data patterns, qualitative research
instruments were applied. Qualitative research instruments are generally well suited for identifying phenomena, tendencies and patterns in data (Gelling, 2015). The study then turned to a quantitative research instrument to triangulate the data further and nuance the theory building. Factors identified with the qualitative research instruments could then be tested quantitatively.

3.3 Research design

This section describes and justifies the design of the study and the instruments used to gather and analyze data.

3.3.1 Case study

The research has been conducted with a single case study approach. A case study was considered the most suitable strategy because of its effectiveness when studying phenomena in their real-life context. Both to generalize empirical evidence to build new theory and to draw conclusions from theory to the specific case. These attributes of the strategy were considered critical in understanding how to improve a material supply system in the pharmaceutical industry in a research and development plant. The study was compromised to a single case due to the lack of suitable case companies in reasonable proximity and the restricted time frame. Also, in depth investigation was prioritized over width and enabled by committing to a single case over multiple. Further, the case company selected met all necessary conditions to conduct the study (Chapter 3.3.2).

In previous chapters, the existing body of research on design of material supply systems has been described and so has the context that the research originates from. Further, the pharmaceutical industry within research and development plants has been described with its features and its unique context that the material supply system, in this case, is influenced by. The influence of this specific context on the design of the material supply system appears to be an unexplored research area. With the aim of illuminating the interface between the phenomena and the context, (material supply systems in the pharmaceutical industry within research and development plants), the following research questions where formulated;

1. What factors are critical to achieve a cost-efficient service level in a material supply system for consumable lab supplies within a research and development plant in the pharmaceutical industry?

2. How could a material supply system for consumable lab supplies within a research and development plant be designed to achieve a cost-efficient service level in the pharmaceutical industry?

The design of the study and the choice of research instruments were selected with consideration to the phenomena under study, the existing body of theory and the characteristics of uncertainty regarding the phenomena and the contextual influence.

The research has been explorative in nature in its endeavor to explore the conditions affecting the design of material supply systems within the pharmaceutical industry in research and development plants (Patel & Davidson, 2011). To understand how the pharmaceutical industry differentiate from other industries, unknown industry specific factors needed to be identified. To identify those factors and understand their effect on
the system, verbal or qualitative methods were the most well suited to attain and analyze the data (Gelling, 2015). With the crucial industry specific factors identified and their respective importance valued, there was a need for a different research approach, to find the relationship between the industry specific factors and the general design factors for material supply systems. Data needed to be systematized and models were created to calibrate the values of the factors. Thus, the research was transformed towards a more descriptive orientation (Ivey, 2016). When the verbal factors were translated into numbers, the analysis aiming to understand their relationship was conducted through numerical tools. Thus, the data patterns were analyzed with quantitative research models (Watson, 2015).

3.3.2 Case Selection

The case selection was conducted using purposive sampling, meaning that the case company was selected on the basis of knowledge about the company and the background of the study (Williamson, 2002). As described previously, a material supply system is not considered a key business function within the pharmaceutical industry in research and development plants. It is rather a supporting function, but with high enough research volumes, the function makes up a considerate logistical engagement. Thus, to ensure that the study was fed with sufficient data, the case company had to be of substantial size. AstraZeneca’s research and development plant in Gothenburg was at the time of the study employing roughly 2400 workers of which approximately 1200 worked as researchers. Together they consumed lab supplies in the order of dozens of millions of SEK on a yearly basis. The system was therefore considered extensive enough to accommodate the research (Table 2).

AstraZeneca is a global-research based pharmaceutical company with focus on heart and vascular, metabolic diseases, oncology, respiratory tract, autoimmunity, neuroscience and infection. In 2016 the company invested approximately 50 billion SEK in research and 25% of the company’s research is situated on the site in Gothenburg (AstraZeneca, 2018). Apart from the size, the global aspect was also important in the selection to ensure that the result of the study was internationally viable. The company operates both under Swedish and international laws (AZethics, 2018). That implies that the company must operate in accordance with the Swedish medical product agency (Läkemedelsverket, 2018) and the international standards: GMP, GLP and GCP (Benner, 2009). Further, the plant has a wide scope with many different research disciplines and houses everything from basic general research to production of products for testing. Hence, it incorporates most aspects of what can be found at research and development plants within the pharmaceutical industry. The industry specific factors identified can therefore be assumed to be applicable on an international level.

Table 2: Table with generalized company and plant information.
3.4 Data collection

The selection of methodological instruments to gather theoretical and empirical data to this study was based on the research design and the prevailing circumstances at the case company. To enhance the validity of the study, multiple sources of data were used to get a more nuanced appreciation of the problem area. Thus, the results were triangulated and tested vis-a-vis to validate the results (Williamson, 2002; Yin & Nilsson, 2007). The instruments used were: literature review, observations, interviews, focus groups and documents. There is no general combination of methodological instruments to best suit a case study. Instead, the instruments should be selected in a tailor-made combination to suit the specific circumstances of the case in study. However, the selected instruments of this study are generally suitable for case studies in various combinations (Olivié & Pérez, 2014).

3.4.1 Literature review

Together with the case company’s specific context, the literature review has formed the backbone for this study. The literature review has been conducted mainly in the initial phase of the study with purpose to form the theoretical framework, investigate the gaps in theory which the study aims to fill and to give a foundation for the chosen methodological approach and instruments. A critical approach has been taken when analyzing the retrieved data and several sources have been reviewed to ensure the credibility of the presented theories (Williamson, 2002). Further, the literature review has formed the base for the theoretical framework that has provided the theoretical input to the analysis which was used to understand and validate the empirical findings of the study (Yin & Nilsson, 2007).

3.4.2 Interviews

Interviews are commonly used to retrieve qualitative data regarding the phenomena in their real-life context (Talmy, 2010). In this study, open interviews were used to collect data regarding the following topics. The opinions of the workers within the material supply system at the case company. The problem area with probable causes and ideas for how the system could be improved. Information about how the work activities in the material supply system is designed and was performed at the time of the study. The topics where investigated with questions based on how and why to favor discussion and reasoning aiming to get a full understanding of the material supply system. Further, the interviews helped getting a better overview of the space configuration of the facilities at the case company.

Open interviews are flexible in nature and more of a conversation with a given direction rather than a technical questioning. It allows unexpected topics to arise and be discussed and does not need to follow a specific script. Interviews in general, are a time-consuming but effective method of getting the most data out of a respondent. Due to the small group of individuals with relevance to the topic in this case, the time aspect could be ignored in favor of nuanced data. Therefore, all the workers in the material supply system were surveyed in the study and interviewed (Yin & Nilsson, 2007). The interviews served an explorative purpose and were mostly used answering the first research question, but established conditions for the answering of the second research question too.
Method and implementation

Table 3: Overview of executed interviews.

<table>
<thead>
<tr>
<th>Occasion</th>
<th>Worker A</th>
<th>Worker B</th>
<th>Worker C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1h</td>
<td>15/1</td>
<td>0,5h</td>
</tr>
<tr>
<td>2</td>
<td>1h</td>
<td>16/1</td>
<td>0,5h</td>
</tr>
<tr>
<td>3</td>
<td>1h</td>
<td>17/1</td>
<td>0,5h</td>
</tr>
<tr>
<td>4</td>
<td>1h</td>
<td>18/1</td>
<td>0,5h</td>
</tr>
<tr>
<td>5</td>
<td>0,5h</td>
<td>31/1</td>
<td>0,5h</td>
</tr>
<tr>
<td>6</td>
<td>1h</td>
<td>1/2</td>
<td>1h</td>
</tr>
<tr>
<td>7</td>
<td>1h</td>
<td>15/2</td>
<td>1h</td>
</tr>
<tr>
<td>8</td>
<td>1h</td>
<td>21/2</td>
<td>1h</td>
</tr>
</tbody>
</table>

3.4.3 Observations

The observations in this study have been conducted with an unorganized and participating structure. By participating in the work activities under study and observing the workers, an overview and understanding of the activities in the system has been attained (Bering Keiding, 2010). The method is beneficial to utilize to gain insights of the system that the workers would not express in an interview and to understand how the work activities are related and affect each other. It is a good method for gaining a holistic view of the problem area and to understand the role played by the unit of observation in the bigger system. Observations often offer alternative information regarding phenomena that is not expressed in the work activity description. Observations can investigate how and why errors occur, their effects and how they are managed etcetera (Yin & Nilsson, 2007).

The employees surveyed for the interviews were also surveyed for the observations. Descriptions of the work activities articulated in the interviews could therefore be investigated further and vice versa which triangulated the results. Furthermore, interesting aspects which were not described in the interviews were identified in the observations. The observations also enabled a comprehension of how the phenomena described in theory had been translated and merged with the context specific conditions by the case company to form the existing material supply system. The observations were mostly used to gather qualitative data which was needed to answer the first research question but established conditions for the answering of the second research question too.

Table 4: Overview of executed observations.

<table>
<thead>
<tr>
<th>Observations</th>
<th>Worker A</th>
<th>Worker B</th>
<th>Worker C</th>
</tr>
</thead>
<tbody>
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<td>15/1</td>
<td>2h</td>
</tr>
<tr>
<td>Occasion 2</td>
<td>4h</td>
<td>16/1</td>
<td>2h</td>
</tr>
<tr>
<td>Occasion 3</td>
<td>6h</td>
<td>17/1</td>
<td>2h</td>
</tr>
<tr>
<td>Occasion 4</td>
<td>6h</td>
<td>18/1</td>
<td>2h</td>
</tr>
<tr>
<td>Occasion 5</td>
<td></td>
<td>2h</td>
<td>31/1</td>
</tr>
</tbody>
</table>
3.4.4 Convergent interviews and Focus groups

Convergent interviews with key managers where used in the initial phase of the study to define the boundaries and aim of the study. Further, a brief introduction of the material supply system was conducted. Convergent interviewing can be used when the interviewer has yet to define what information needs to be collected during the study. The purpose is to find out what is regarded important within the problem area. Later these insights should be tested with other methodological instruments (Williamson, 2002). The participants in the last two convergent interviews and all the focus groups were the same three managers. They were sampled due to their expertise in the case company and the material supply system as described in Chapter 3.1.1. in accordance with the theory on purposive sampling (Williamson, 2002).

The problem areas identified in the convergent interviews where later discussed in a more structured, yet exploratory sense in focus groups. A focus group is a group of people with insight to the topic that openly discuss or engage in brainstorming around the questions that the interviewer brings up (Olokundun et al., 2017). It builds on the theory that individuals can form better opinions and theories if they have other opinions to base theirs on and extend them further (Williamson, 2002). Apart from assisting in answering the research questions, the focus groups also culminated in research design guidelines. The aim and purpose of the study was discussed initially and later the methodological approach and the progression. The focus groups have also contributed in data triangulation to validate input from the interviews, observations and documents (Murdoch et al., 2010). Thus, the focus groups have had a great influence throughout the study. The convergent interviews and the focus groups has been explorative in nature and resulted in mainly qualitative data. They were used mainly to direct the study and to answer the first research question but also established conditions for the answering of the second research question.

Table 5: Overview of executed convergent interviews and focus groups.

<table>
<thead>
<tr>
<th>Occasion</th>
<th>Convergent interviews / Focus groups</th>
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<td>1h</td>
<td>9/1</td>
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<tr>
<td>1h</td>
<td>15/1</td>
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<tr>
<td>1h</td>
<td>18/1</td>
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<td>1h</td>
<td>22/1</td>
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<tr>
<td>1h</td>
<td>25/1</td>
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<tr>
<td>1h</td>
<td>6/2</td>
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<tr>
<td>1h</td>
<td>13/2</td>
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<td></td>
<td>1h</td>
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<td>19/2</td>
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<td>6/3</td>
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<td>20/3</td>
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<td></td>
<td>26/3</td>
</tr>
<tr>
<td></td>
<td>23/4</td>
</tr>
</tbody>
</table>

3.4.5 Documents

The use of documents is an almost inevitable element in a case study. The scope of the study often does not leave room for gathering all the necessary data first hand why existing documents are usually consulted. As the data retrieved from documents have been gathered by someone else, most likely with a different purpose than the current study, it should be critically reviewed (Yin & Nilsson, 2007). The documents in this study was required to contain high amounts of historical data regarding the material supply system. The data was quantitative and the analysis of it was descriptive in nature.
and performed in Excel using preprogrammed formulas and the formulas introduced in the theoretical framework. Based on the phenomena detected and investigated with the other methodological instruments, the effects of calibrating the critical factors was further explored using data from the documents. The documents were mainly used to answer the second research question. The documents in this study mostly consist of reports generated by the contracts (responsible for the material supply system), ERP-system. The reports contained information that could be used to; calculate demand, investigate inventory assortments, calculate delivery lead-times and monitor inventory levels in the material supply system. All data retrieved from the documents was from the year 2017 to get a full year’s report. The data was used to identify phenomena and conduct quantitative testing of phenomena identified in the literature review, interviews, observations and focus groups.

3.5 Data analysis

The data analysis in this study has been fed with input from four different research instruments. The nature of the data has varied from explorative and qualitative to descriptive and quantitative. The analysis has aimed to both identify patterns in the context and generalize those patterns to build theory, and to use theoretical concepts and apply those to the case. However, regardless of source, aim and the nature of data, the analysis has gone through the same three steps; data reduction, data display and conclusion drawing (Miles & Huberman, 1994). The data categorization has also followed a common standard in accordance with the theoretical framework. The data was categorized under the different design parameters, contextual influence, technical tools and administrative resource consumption. The data analysis will be described based on the research instruments. The conclusions generated from the data analysis was utilized continually throughout the data collection and analysis to guide the study onwards in iterative cycles.

3.5.1 Observations

The unstructured observations resulted in large amounts of observation notes mixed with unformulated mental notes which there had not been enough time to write down during the observations. After each observation session, this data was transcribed and structured in accordance with the categories described in Chapter 3.5. The data from the observations was mainly qualitative, describing verbal phenomena and behaviors by the workers in the material supply system, but also the physical layout. In the initial phase of the case study, the purpose was to collect solely explorative data but at the end they served a descriptive purpose as well to validate and build theory. When data from several observations had been accumulated, the text was condensed to increase the information density. Further, the information was coded to reflect the identified data patterns concerning the observed phenomena and enable theory building. With the data patterns identified and displayed, conclusions could be drawn and presented towards results from the other methodological instruments to enable triangulation of results (Williamson, 2002).

3.5.2 Interviews

The processing of data retrieved from the interviews was similar to that of the observations. All interviews were followed up with a transcription and categorization of the interview notes in accordance with the description in Chapter 3.5. The data from
the observations was mainly qualitative, describing verbal phenomena with special focus on the workers opinions regarding the system and their described work activities in the material supply system. Further, they made a few quantitative claims regarding ratios of demand and goods assortment. In the initial phase of the case study, the purpose was to collect solely explorative data but at the end they served a descriptive purpose as well to validate and build theory. When data from several interviews had been accumulated, the text was condensed to increase the information density. Further, the information was coded to reflect the identified data patterns concerning the studied phenomena and enable theory building. With the data patterns identified and displayed, conclusions could be drawn and presented in relation to results from the other methodological instruments to enable triangulation of results (Williamson, 2002). The quantitative claims from the interviews was not considered credible enough to build theory but was used as embryos of phenomena that was tested with historical data from the ERP-system.

3.5.3 Focus groups

The focus groups constituted a part of the data analysis in itself. Data from the other methodological instruments was discussed and analyzed in the group of experts that the participants constituted. The implications of the conclusions drawn based on other research instruments and their mutual relationships was discussed and analyzed. The focus groups were explorative in nature and generated qualitative data based on verbal reasoning. The output, often being analyzed in the group, still needed further processing as follows. After every focus group, the resulting notes where transcribed and structured in accordance with the categories described in Chapter 3.5. The data was then condensed and coded to be compatible with the qualitative data generated by the other research instruments. The coded data was finally used to draw conclusions regarding the studied phenomena to build new theory (Miles & Huberman, 1994).

3.5.4 Documents

The document analysis has been descriptive in nature and managed quantitative data in Excel in accordance with a positivistic philosophy. The document analysis has been intended to identify patterns in data regarding the studied phenomena to generalize and build theory. Further, it has been used to validate and falsify qualitative claims generated by the other research instruments. The data retrieved from the case company as documents, comprised vast data volumes, and was far too complex to analyze without computer capacity. The ERP-system generating the reports could export the data to Excel which was selected as the tool for conducting the analysis. However, all data needed to analyze the phenomena could not be generated in the same report but had to be separated into several. Therefore, the data needed to be reduced and displayed which was done by sorting it with codes which required suitable formulas. The Excel formulas; SUMIFS, VLOOKUP, NORMSINV and MEADIAN were used to interlink and sort data from different sheets in accordance with selected codes. Further processing of the data was conducted to extract the variables needed for the formulas introduced in the theoretical framework. With the data coded and processed, it was converted from sheets into tables and diagrams to allow for an overview and interpretation of the data. Based on the tables and diagrams, the data was analyzed and conclusions were drawn.
3.6 Research quality

To ensure the quality of this study, reliability and internal, external and construct validity has been considered when designing and executing the research. To increase the quality of the results, the method and implementation of the study has been described in this chapter. Both to enable repeating of the study in similar conditions, and evaluation of the selected methods (Williamson, 2002).

The internal validity is relying on the research instruments measuring what is supposed to be measured. Meaning that the effects on a phenomenon that are identified by the research instrument can be connected to the correct cause. To ensure that this study has been conducted with high internal validity, research instruments where selected that are universally recognized as effective for this type of research (Yin & Nilsson, 2007). Further, the results where triangulated by applying several research instruments to study the relationship between cause and effect which reduces the risk of identifying the wrong cause (Wisdom et al., 2012).

The quality of a study in regard of construct validity refers to how cause and effect is related in theory regarding a phenomenon compared with how it is related in the real-life context to the same phenomenon. The abductive approach in this study has been vital to secure a close connection between reality and theory. The theoretical framework has been updated in iterative cycles throughout the execution of the case study. Thus, the empirical findings have been supported by theory by ensuring that the methodology has measured the construct of the phenomena consistently with the theory (Wisdom et al., 2012; Williamson, 2002).

The external validity is a measurement of the generalizability of results to other cases with a similar context. In this study, the external validity has been enhanced by using clear delimitations for the study and the applicability of its results, to an industry within a specific business area which is regulated by law which makes the context standardized. The explorative elements of the research have complicated the theory matching between empirical findings and theory. Empirical findings have instead been validated by triangulation (Williamson, 2002). Further, communicative validity has been applied meaning that experts from the case company and the research discipline has been consulted on the reasonableness of the results (Rutherford et al., 2010).

The reliability of the study represents how accurate the results of the study are and if they can be achieved again. The reliability has been enhanced by describing the methods which enables repetition of the study and by selecting proven methods. Further, the qualitative methodological instruments where applied multiple times to calibrate the results and ensure that confounding variables were sorted out. Also, the quantitative data comprised a full year which ensures that the results are redundant to periodic fluctuations (Williamson, 2002).
Findings and analysis

4 Findings and analysis

In this chapter, the empirical findings retrieved from the case company are presented and analyzed, structured on the research questions and based on the theoretical framework. The chapter is introduced with a description of the existing functions, and the material supply system layout at the case company which establishes the current conditions.

4.1 Case company

The material supply system for lab supplies at the case company AstraZeneca is operated by a contractor, VWR. The system employs three full time workers with assistance from adjacent functions. The value of the lab supplies turned over per year is roughly 15 000 000 SEK and the system comprises 1 568 unique articles. The plant has one goods reception where all goods delivered to the plant are received. The goods reception is operated by another contractor, Sodexo, that sorts the goods and facilitates the internal deliveries to all recipients. The material supply system has 13 inventories on the plant which get deliveries from the goods reception that the three workers unpacks, sorts and places on the assigned shelf space for each article. The inventories comprise a buffer that is needed to accommodate the required lead-time for internal deliveries to the plants 62 PoU (points of use). All PoU are assigned to one specific inventory due to the cost center structure of the company. The PoU is in practice a second inventory level, located in the laboratories from where the researchers collect their lab supplies.

All the inventories and PoU at the plant have assigned minimum and maximum inventory levels for all the articles they accommodate. The minimum level represents the order point, the difference between the maximum and the minimum level represents the order quantity in the system. The workers in the system are responsible for cycle counting the articles in the PoU at given intervals. When a minimum inventory level is underrun, the workers enter the number of articles which are left in stock to their ERP-system. The ERP-system automatically places an order to one of the 13 inventories of the number of articles needed to reach the maximum level. When the cycle counting is complete, the system generates a picking list of all the articles which were ordered. The picking list is later printed and used to pick the articles in the inventory to refill the PoU.

The stock levels for the articles in the inventories are monitored by the ERP-system. When an order is received from a PoU to an inventory, the ordered amount is subtracted from the inventory balance. If the minimum inventory level is underrun in the ERP-system, the system automatically generates an order of the required number of articles needed to reach the maximum level. Most of the orders placed are supplied by the contractor’s own external inventories. When that is the case, the automatically generated order is automatically dispatched at a given time. Usually, the contractor delivers the next day. If the articles are supplied by another supplier, the order is extracted from the system and sent manually. That implies that the ordering process often requires no administrative work at all and when orders need to be redirected to other suppliers, the administrative resources required are limited. The plant that this study was conducted at has 250 operating days per year and an inventory interest of 20% per year can be applied for goods in inventory.
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4.2 Research question 1

What factors are critical to achieve a cost-efficient service level in a material supply system for consumable lab supplies within a research and development plant in the pharmaceutical industry?

The critical factors to achieve a cost-efficient service level in a material supply system for lab supplies in the context of this study, is a combination of general material supply system design factors and context specific factors (Figure 11).

![Design Purpose, Boundaries, Design Parameters, System Dynamics, Facility Conditions]

The design purpose should be to achieve a cost-efficient service level. Regulations affecting the system should be managed in the initial design phase. The design parameters should be adapted to accommodate uncertainty and variation. The article assortment needs to be wide, dynamic and responsive. Great potential to improve the system efficiency, simplified with centralization.

Figure 11: The critical factors in a material supply system in the pharmaceutical industry in a research and development plant to achieve a cost-efficient service level.

4.2.1 Design purpose

A critical factor when designing a material supply system with a cost-efficient service level is to start with a well aligned purpose for the matter. Historically, that has not been the case for research and development plants in the pharmaceutical industry where cost usually has been neglected (Shukran et al., 2017; Nematollahi, 2018). At the case company, the purpose of the design has been to enable a high service level towards the scientists and to accommodate the company’s cost center structure. The research areas consuming lab supplies at the plant is structured under 13 different cost centers. One of the workers explains that the inventory structure with 13 different inventories is the result of the company wanting to keep the budgets separate. Using the cost centers as a design factor has been vital for how the work activities in the system were set up and the current function of the system. The participants in the focus group want to eliminate the influence of the cost centers as a design factor. The high service level is still important but they wish to pair it with cost-efficiency instead. The workers in the system certify that the influence of the cost centers have complicated their work in several aspects and that it requires many non-value adding activities that will be described further in Chapter 4.2.3. Hence, the purpose behind the design of a material supply system in a research and development plant in the pharmaceutical industry is essential to fulfil a cost-efficient service level.

4.2.2 Boundaries

A critical factor when designing a material supply system in a research and development plant in the pharmaceutical industry, concerns the laws and regulations that apply and affect the selection of supplies and the activities in the system (Shukran et al., 2017; Benner, 2009). Depending on research area, the requirements differ and the strictest requirements, which would cover all areas on the plant, would be too expensive to implement plantwide. Consequently, the standards affecting the work activities will differ in different environments on the plant. The workers in the system state that the
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requirements from laws and regulations affect many of their daily work activities. However, they say that the requirements can be managed with little effort if the work environments and system layout is appropriate. Therefore, the regulations should be considered in the initial design phase of the system.

Before entering a laboratory for delivery to a PoU, the workers need to follow certain procedures ranging from wearing lab coats, glasses, special shoes, washing their hands and standing in air showers. The strictest classification also requires the goods to be sprayed with a bactericidal agent that needs to work 15 minutes before entering the research area. The observations revealed that most of these activities barely slows down the work due to the workers good routines and the smart design of entrances to the laboratories which features the necessary gear for the specific environment. However, the air shower and particularly the bactericidal spray were time consuming. The air shower required 45 seconds work to be effective. The spraying was conducted in connection to the laboratories that required it. The workers had no other work activities in that area and had to wait or go somewhere else while the agent worked which was inefficient. Therefore, it would be beneficial to locate the spraying station in proximity to an area where other work activities are conducted.

Apart from the affected work activities when handling the articles, the requirements also cover the articles themselves. Again, different standards are applicable depending on the intended research. Generally, the consequence of following the standards is that the articles are relatively expensive and sometimes scarce. Therefore, few suppliers are available which sometimes result in long delivery times and delivery costs. The documents reveal that most deliveries are conducted within a few days but articles that stand outside the contractor’s Swedish assortment may take several weeks. Delivery costs are rarely applicable and affects only 174 out of 27 905 orders in 2017, but the highest is of over 6 000 SEK. The delivery times and costs implied by following high standards should be considered when dimensioning safety stocks and order quantities to minimize cost and to maintain the service level (Jonsson & Mattsson, 2016).

4.2.3 Design parameters

The design parameters set the conditions for, and guides the work activities in the material supply system to uphold the functionality. Therefore, they are crucial factors to maintain a cost-efficient service level. The inventory structure describes how the number of inventories affects the system. The order point and service level and their internal relationship is analyzed and the case company’s relation to the terms is described. The order quantities are evaluated and analyzed from a theoretical and empirical standpoint.

Inventory structure

The inventory structure at the case company is, as described in Chapter 4.2.1, the product of the cost center structure. With 13 inventories at a limited area, the structure is defined as decentralized. A decentralized structure generally has favorable conditions for transports but higher inventory holding costs compared with a centralized. The number of inventories should be justified by having an economic balance between the two associated costs (Lee & Jeong, 2009; Jonsson & Mattsson, 2016; Hartman & Dror, 2003). Normally when the cost of transport and the inventory holding cost are weighed towards each other, the transports refer to external deliveries requiring vehicles and
long-distance travels (Jonsson & Mattsson, 2016). However, at the case company all deliveries to the PoU are internal and executed using trolleys. Therefore, the hypothetical difference in delivery distance, cost of transport equipment and the total cost of transport, is limited regardless of inventory structure.

Further, the potential advantage of shorter delivery distances is not fully leveraged because during the observations it appeared that the workers usually doesn’t depart from the inventories towards the PoU. Instead they departed from their personal offices which they return to between deliveries. In the interviews they explain that they need to go back to print a picking list before going to a new inventory to start the next delivery. Hence, the potential theoretical advantage of the shorter transports is not utilized in practice. However, the orders from the PoU are usually placed one day in advance of deliveries. A few times during the observations, articles that were not ordered and included in the delivery, had underrun their minimum inventory level during the day. With the decentralized structure, an extra delivery round could easily be executed to fill up the PoU with the inventory in close proximity.

The workers in the system have a negative standpoint towards the decentralized inventory structure. One of them says that an argument for the advantage of having 13 inventories has been that;

“The inventories assortments are specialized for the PoU they supply and carries only the articles consumed there, which simplifies order picking”.

As different buildings around the plant are specialized in different research areas, the idea is that they require different article assortments. Amongst the workers however, consensus prevails that most articles are present in most inventories and that they mostly pick the same articles regardless of inventory, which they claim makes the “specialization” argument invalid. During the observations it was indeed noted that many articles are recurring on the picking lists in different inventories. However, the documents reveal that out of the 1 568 articles registered in the system, 1 119 is present in only one inventory. That indicates that the inventories are more specialized than perceived. However, the order picking is not only affected by the assortment of articles, but the frequency of consumption amongst the articles too. Further analysis of the data revealed that the articles only present in one inventory accounted for a very small portion of the consumption. As an example, articles present in three inventories or more was consumed in on average 384 units per inventory during 2017 compared with 28 units for the ones only present in one inventory. Further, 412 articles had not been consumed at all during 2017 and out of those, 382 are only present in one inventory which is a strong overrepresentation (Figure 12). Consequently, the inventories are quite specialized for the PoU they supply, but the work activities do not benefit of this specialization because the frequently consumed articles are the standard articles that are present in several inventories.
An aspect of the material supply system which all three workers brought up and two regarded as one of the main problems, is that scientists are allowed to pick supplies straight from the inventories instead of the PoU. That implies that the inventory balance in the ERP-system, described in Chapter 4.1, is not accurate and that the workers have to conduct cycle countings every time they pick orders. The scientists pick from the inventories rarely and during the observations, the inventory balance was incorrect just a few times. Still, to uphold the service level for all articles, the inventory balance, which is used to dispatch the orders, must be up to date. Utilizing work hours to cycle count articles continually on two inventory levels is an example of inbound process inefficiency which is the main challenge in material supply systems (Li et al., 2016). In the focus group, the participants which has authority to make decisions regarding the process, said that if the structure would be centralized, the inventory could be locked and scientists would not be granted access. Further, they explained that the reason why self-service is currently allowed is that, if something is missing in the PoU, the scientists must be able to get it straight from the inventory. With 13 inventories, the three workers cannot accommodate fast enough service from each inventory, but with only one, that would be possible.

When goods are delivered to the plant, they are split, sorted and delivered to the function on the plant that has ordered them. Internal deliveries are conducted continually throughout the day and do not follow a particular schedule. Two of the workers say that the internal deliveries from the goods reception to their inventories in the current state is problematic. The contractor’s two ERP-systems are not interconnected which results in the contractor responsible for the material supply system having to manually monitor their 13 unpacking stations to know when they have got a delivery. This becomes an issue when there is a shortage in the inventory and an order from a PoU of the same article. If the article is ordered to the inventory but has yet to arrive, the workers must manually go and monitor the drop off area during the day to complete the delivery to the PoU as soon as they get the article. This is both time consuming and frustrating for the workers that must reroute their work.

“We may have to return several times during a day”,

-says one of them. During the observations, this scenario occurred twice and indeed was frustrating and time consuming. Having to physically be present at 13 locations to monitor deliveries is another example of inbound process inefficiency which generally causes the most problems in material supply systems (Li et al., 2016). An aspect that
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aggravates the problem is the high number of inventories. With a centralized structure with only one inventory, all deliveries would be monitored every time someone returns to work in the inventory.

Order picking is the most resource consuming activity in a material supply system (Li et al., 2016). At the case company, all articles have specific designated shelf spaces in all inventories which can be found by using an article list. The observations yielded that using the list often required about a minute compared with a few seconds when the worker had memorized the position of the article. For the material supply system to function in practice, it is necessary that the workers have memorized most locations for the articles to enable a reasonable picking speed. One worker mostly resides to the same portion of inventories and state that she feels confident in finding most of the articles from memory. However, she does recall having difficulties in the initial phase of the employment. The other two workers have more flexible assignments and work in all inventories occasionally. Both state that they have problems memorizing article positions in inventories they do not visit frequently. During the observations it was noted that all three workers work unhindered in the largest inventory which is frequented the most. The high number of inventories aggravates the difficulty of finding articles because it is hard to establish standards that applies to all 13 inventories. Further, the workers frequent the individual inventories much less compared with if they only had one inventory which all deliveries departed from. Finally, as many articles are located in several inventories, the total number of locations to memorize is higher with the higher number of inventories. The current inventory structure makes it particularly difficult for new employees and, historically, the system has had a considerable staff turnover which has caused problems. A digital command system which guides the workers was discussed in the focus group but was promptly dismissed for the limited scope of the material supply system at the plant. Centralizing the inventory structure to one inventory would simplify and make the order picking less resource consuming.

Based on the above described aspects of the material supply system that are affected by the inventory structure (Figure 13) a centralized inventory structure with one inventory appears as the most cost-efficient to maintain a given service level. According to Eppen (1979), the work efficiency in material supply systems usually increases progressively with the size of the inventory. Reducing the number of inventories and increasing the size of the remaining is therefore advantageous. Further, the participants in the focus group argue that they experience a threshold for streamlining the processes with the current decentralized structure. The information needed to make decisions is hard to grasp with the 13 inventories which makes it difficult to implement changes.

Figure 13: Aspects of the decentralized inventory structures that affects the material supply system.
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Order point and safety stock

The order point and safety stock constitute the foundation of the total inventory level in the material supply system which affects cost and service level which makes them crucial factors in a material supply system. The order points are, in the case company, entitled the minimum inventory levels. The levels are supposed to be established by the workers in the system and have been set up by especially two of them that has been working in the system for a longer time. The minimum inventory levels comprise the safety stocks and are therefore decisive for the service level in the system. The two workers state that they have based the minimum inventory level for each article in each location, on their experience of the demand, the delivery lead-time and their “gut feeling”. That is a simple and common strategy for dimensioning order points and safety stocks (Jonsson & Mattsson, 2016). However, the observations in the inventories indicated deficient consistency regarding the minimum inventory levels based on the criteria in the workers definition. Some articles appeared to have very high inventory levels compared to others based on demand and delivery lead-time. After further interviewing it was obvious that there were no clear guidelines for how to interpret the strategy. They said that the fundamental idea is that the order point should not be too high which would be costly and not too low which would jeopardize the service level. However, the high availability focus, often prominent in material supply systems in research and development plants in the pharmaceutical industry, appeared pervasive in the case company too (Nematollahi, 2018). The spontaneous perception after the observations was that the minimum inventory levels where generally high and when asking why, the answers where:

“It must never run out” and “It always has to be there”.

Also, during the observations, old versions of the articles was found in the PoU a few times which turned out to have been stored for several years which certifies the inconsistent, generally high levels. In the focus group this aspect was discussed and one participant described a room on the plant which they had filled with articles which was no longer demanded with high inventory levels remaining in stock. Also, many articles have expiry dates which are passed occasionally and results in articles being discarded. Currently these costs are not tracked by the company. Solutions were discussed to prevent the high number of articles turning obsolete in the future and it was agreed that the minimum inventory levels could be lowered in many cases with very low risk of decreasing the service level considerably. Both because the minimum inventory levels are high, and because the articles are stocked both in the inventory and the PoU and oftentimes in many of each which result in many layers of redundancy. An article running out plantwide is therefore very improbable. To get a fuller comprehension of the supposed inconsistency and over dimensioning of the minimum inventory levels in the inventories, the documents from the contractor’s ERP-system was investigated. The “gut feeling” aspect was eliminated from the definition and the minimum inventory level was related to the rate of consumption and the delivery lead-time (Figure 14). The service level is represented by the service ratio which was calculated by dividing the minimum inventory level with the consumption during the delivery lead-time for each article. A high service ratio indicates that the minimum inventory level is high in relation to the consumption during the lead-time which reduces the risk of an article running out. To generate valid results, only articles which were consumed at least once during 2017 and had a minimum inventory level of at least one was included. For the
remaining articles, the average service ratio was 69.28 with a standard deviation of 302.34. That means that the minimum inventory levels for the articles in the system is on average, almost 70 times higher than the consumption that it is supposed to cover, with very low consistency. However, the low consistency and high minimum inventory levels in relation to consumption during lead-time, is partly due to the high portion of articles in inventory with very low rates of consumption. For those with lowest consumption rate, even one unit as minimum inventory level renders a high ratio. For articles that were consumed in at least 100 units during 2017, the minimum inventory level divided by consumption during lead-time was on average 15.77 with a standard deviation of 64.09. The same ratios for articles consumed in at least 500 units a year were 7.65 and 15.58 and for those consumed at least in 1000 units a year the ratios were 7.15 and 17.02. This means that for the articles which are consumed more frequently, the relation between minimum inventory level and the consumption during lead-time decreases. However, the standard deviation remains relatively high which strengthens the hypothesis of inconsistency in the dimensioning of the minimum inventory levels.

A critical factor to achieve a cost-efficient service level is to dimension the safety stock, hence the order point, to a level which is economically justifiable. The most accurate assessment of the service level requires the standard deviation of the consumption rate during delivery lead-time to be considered (Jonsson & Mattsson, 2016). However, the simplified model described above, provides an overview of the potential result when dimensioning the levels with an unclear interpretation of the purpose. The definitive consequences of which, is that articles turn obsolete and must be discarded which is costly and that more volume than needed is occupied to stock the inventories. To illustrate what a justifiable service level and the associated service ratio can be, the following examples are conducted. A hypothetical article with a yearly demand of 31 units, an order quantity of 1 unit and a delivery lead-time of 1.5 days, would with a service level of 90% have an order point of 1 unit. The associated service ratio would be 5.81. If the same article had a yearly demand of 1 000 units and an order quantity of 25 units, the order point would be 23 and the service ratio would be 6.22 (Jonsson & Mattsson, 2016). Consequently, a clear definition for the purpose of the order point and safety stock, and guidelines for how to dimension the levels, is crucial to reduce inconsistency in service level and the inventory holding cost.
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Order quantity

The order quantity is the number of units which is ordered when the order point is reached. Hence, the average inventory level, which corresponds to the inventory holding cost, should in theory be half of the order quantity added to the safety stock (Alstrøm, 2001). The order quantity’s direct effect on the inventory holding cost makes it a critical factor to achieve a cost-efficient service level. At the case company, the order quantity is represented by the difference between the maximum inventory level and the minimum inventory level which is set for each article by the workers. The maximum levels have, just like the minimum levels, been calibrated by the two workers with the longest employment. The order quantity that emerge between the two levels is, according to the workers supposed to correspond to delivery lead-time, demand, packing size and delivery cost, which is sometimes applicable as described in Chapter 4.2.2. However, there are no established criteria for how those factors should be combined to render the order quantity and the workers have instead interpreted them individually. One says;

“The order quantity in the inventories should equal the sum of all order quantities for the same article in all PoU that the inventory supplies”.

The other worker disagrees while hesitating to that statement. Further, both workers associate the order quantity to the service level in the system and says;

“It is better to keep it a little higher so that the articles do not run out”.

In theory, the order quantity is not described as a factor with substantial effect on the service level, especially not with infrequent orders (Jonsson & Mattsson, 2016).

The participants in the focus group state that they consider the total inventory level too high and suspect that the order quantities are one of the underlying reasons. During the observations the order quantities indeed appeared high and oftentimes the generous assigned shelf space was not sufficient to absorb the deliveries. As a consequence, goods had to be stored in other areas. This resulted in unnecessary handling and confusion in the inventories which is a common problem in inventory handling (Tracey, 1995). This phenomenon was also visible in the PoU. The effect of having a higher than needed inventory level at all 62 PoU compared with the much fewer inventories has an aggravated effect on the inventory holding cost (Lee & Jeong, 2009).

To get a fuller comprehension of the general size of order quantities utilized in the case company, the documents retrieved from the ERP-system were consulted. If summarizing the minimum inventory levels on the plant, the total number of units is 20 932, or on average 8,16 units per article. The sum of all maximum inventory levels is 49 594 units or on average 19,33 units per article. That gives an average order quantity of 11,17 units per article with a range spanning from 1 to 990 units per order (Figure 15). The proportions of the order quantities can be described by relating them towards the yearly consumption of the articles individually. On average, every article has an assigned order quantity that corresponds to 72% of the yearly consumption which is a very high number that implies an average of less than two orders a year per article. However, that figure is highly influenced by the high number of articles with low consumption rates which are rarely ordered. In practice, most orders placed are for articles with higher consumption rates and cover a much shorter period of consumption.
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As an example, articles that are consumed in at least 10 units per year have order quantities that on average covers 21% of the yearly consumption and for articles consumed in at least 100 units a year, that figure is down to 9%. However, the order quantities could be considerably lowered even for the more frequently consumed articles and particularly for the infrequently consumed articles due to the low ordering costs. The infrequently consumed articles often have higher order quantities than their yearly demand (Figure 15). Centralizing the inventory structure could also simplify a decrease in the relationship between order quantity and yearly consumption. Consolidating the articles to one inventory would imply higher consumption rates per article. As illustrated by the case company, higher consumption enables more frequent orders.

Figure 15: Graphical illustration of the yearly consumption per article and inventory, and order quantities for the articles in the material supply system.

The total inventory level in the 13 inventories should be roughly in the middle between the minimum and the maximum inventory levels which represents 35 263 units for the case company. Currently however, there are 55 175 units in the inventories which is even higher than the maximum inventory level. According to the workers, this is mostly due to historically high minimum and maximum inventory levels which has been lowered but the articles have yet to be consumed. However, many of the articles which have been ordered recently have inventory levels above their maximum levels too which should not be possible. After further interviewing and analyzing the documents it appears that the reason is that the system always orders the amount needed to reach the maximum inventory level when the minimum inventory level is underrun. The difference between those levels is often dimensioned to accommodate the packing size of the article. However, when there is a shortfall, meaning that the minimum inventory level is passed, the ERP-system orders the number of full packages that is needed to reach the maximum inventory level. As an example, suppose that the minimum level is 100 units, maximum is 200 units, packing-size is 100 units and the inventory level is at 101 units. An outtake of 2 units will then generate an order of 200 units because 2 packages are needed to reach the maximum level. In Figure 16, the consequences of the remains of previous orders and the large orders due to fixed packing-sizes that has reached above the maximum level is illustrated. From the perspective of tied up capital, the consequences are that the inventory value in the end of 2017 was 4 988 869 SEK.
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The value of goods consumed over the year was 14 647 977 SEK which gives a turnover rate of 2.94 times per year.

Figure 16: Graphical illustration of the relations between the inventory level, the maximum inventory level and the minimum inventory level.

A theoretically established and accepted method for dimensioning the order quantity is to find the most cost-efficient order quantity in terms of inventory holding cost weighed against the ordering cost (Jonsson & Mattsson, 2016; San-José et al., 2017; Bedyaeva & Kapitanov, 2015). In the focus group it was stated that this optimization is often irrelevant for the case company. They argue that the cost of the extra handling, confusion, packing sizes, low demands and obsolescence is hard to put a general price on and the consequence of large orders why small is preferable. Further, most orders are generated and dispatched automatically by the ERP-system why the ordering cost is arguably zero. Therefore, orders should be as small as possible in general and adjusted in cases where delivery cost or other factors requires it to. Further, it is crucial to establish a fixed order quantity and utilize an ordering system that can accommodate the purpose to disable unintentionally high orders. This will increase the turnover rate and reduce the cost for discarded articles and in the end, the inventory holding cost.

4.2.4 System dynamics

An aspect of material supply systems in the pharmaceutical industry in research and development plants is the wide, unpredictable and varying demand of articles. The system needs to stock a high number of unique articles and be responsive to fluctuations and trends in the research and its associated scientific experiments (Nematollahi, 2018). At the case company, the workers in the material supply system are responsible for calibrating the minimum and maximum inventory levels to accommodate the current demand. In the interviews, the two workers with the longest employments state that they have conducted extensive work to adjust the levels to suit the current demand. The calibration of the levels is considered an ongoing project aiming to continually improve the system. However, the participants in the focus group are concerned about the levels not being lowered fast enough when the demand turns out to be below the expected. The result being overstocked inventories which are hard to manage and articles turning obsolete. One participant in the focus group says that one of the company’s other research plants has a function in their ERP-system that extracts articles that have not
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been consumed for 180 days as an example of how they keep their material supply system dynamic. As described in Chapter 4.2.3, both the minimum inventory levels and the maximum inventory levels are often high which is a symptom of the levels not being adjusted to accommodate the actual, lower demand. Further interviewing revealed that lately, the updating of the levels has been infrequent because of other, more urgent, work assignments. One of the two workers states;

“We have barely had time for it in the last year”.

When the levels are not updated frequently enough, it might be risky to lower them as they might not be increased fast enough if the demand suddenly increases which would cause shortage.

To examine how well aligned the levels in the system are compared with the demand, the minimum inventory levels were studied for the articles which were demanded in 0-4 units during 2017 using the documents (Figure 17). The result is that most of the articles seem to have a minimum inventory level that is not justifiable based on the demand. As an example, 412 articles registered in the system were not demanded at all during 2017, still 206 of those have minimum inventory levels above zero. As these articles seem to no longer be consumed, the minimum inventory levels will most likely not be reached and generate an order why the problem is self-mitigating. However, those levels represent a symptom of the levels not being adjusted responsively enough, which is a problem concerning the articles with still decreasing consumption rates. Instead of smoothly phasing them out of the system, they will most likely reach the minimum inventory level one last time when the demand is close to zero and generate an order which will never be consumed. Even for articles which may be stable at the demand of just a few units per year, the minimum inventory levels are often too high and may represent several years of consumption.

Figure 17: Graphical illustration of the minimum inventory levels for articles with a yearly consumption rate from 0-4.

A critical factor to achieve a cost-efficient service level in the context of this study is to have dynamic system which can accommodate uncertainty and fluctuation in a wide article assortment. Both to reduce the inventory holding cost and to maintain the service level. At the case company, the levels regulating the system have been positioned high to reduce the risk of running out and are not adjusted to answer to demand fluctuations fast enough. This results in unnecessarily high inventory holding costs. To improve, the
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The system needs to be more responsive to demand fluctuations and introduce a function to completely phase out articles that are no longer demanded.

4.2.5 Facilities

The facilities related to the material supply system comprises the premises, the furnishing and the tools and equipment that the workers are utilizing when operating the system. The facilities enable the work activities and constitutes a part of the foundations for the functionality in the system. Therefore, the facilities comprise a critical factor to achieve a cost-efficient service level. However, in the pharmaceutical industry in research and development plants, material supply systems have historically had a low priority, which has been reflected by the associated investments (Nematollahi, 2018). At the case company, this phenomenon is reflected by the facilities. In the interviews, the workers state as examples, that the tools used for unpacking is non-compatible with the purpose. They argue that better trolleys could make their work more efficient and that tablets could digitalize the picking lists and eliminate the need to return to their offices between deliveries to print. During the observations it appears that most inventories have been set up and furnished with leftovers from other processes. The locations in relation to the PoU seems random and the types of shelves vary. Further, the inventories are often not sufficient in size why the unpacking stations often have been located separately somewhere else. This requires unnecessary movement and handling of the goods.

The participants in the focus group are responsible for the investments in the material supply system. Their opinion too, is that the facilities are substandard and reduces the efficiency in the system. They argue that one reason for not having invested to reach a higher standard yet, is the threshold established by the high number of inventories. A decentralized structure implies that lower volumes are handled in each inventory which makes it less profitable to invest (Hartman & Dror, 2003). This is one of the aspects that results in decentralized systems generally being less efficient compared to centralized systems (Tracey, 1995). The focus group states that if a centralization is implemented, investments will be in place to increase the standard of the facilities. Consequently, to achieve a cost-efficient service level, it is critical to utilize purposeful premises, technical equipment and tools. Having a centralized inventory structure with higher frequency of use of the facilities increases the profitability of investments, hence enables them.

4.3 Research question 2

How could a material supply system for consumable lab supplies within a research and development plant be designed to achieve a cost-efficient service level in the pharmaceutical industry?

A material supply system could of course be designed with endless embodiments. The following proposals will be based on the prevailing circumstances at the case company but are assumed to be universally applicable for material supply systems in similar contexts. The critical factors described in Chapter 4.2 forms the foundations for the design suggestion that is presented.
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4.3.1 Boundaries

The laws and regulations that applies to material supply systems in the pharmaceutical industry in research and development plants comes with certain requirements on both article attributes and handling (Benner, 2009; Läkemedelsverket, 2018). The requirements on article attributes are often specifically oriented towards research. Thus, suppliers specialized on research articles are available and can provide most of the articles in the system and are certified to handle and manage the goods. These are advantageous to utilize in close collaboration and as a large player, which a research and development plant constitutes in the context, they may be able to accommodate certain needs and article assortments specifically for the plant. Articles standing outside their assortment must be purchased externally but the number of supplier should be kept at a minimum to maintain a standard.

The inhouse handling requirements of the goods is varying depending on lab environment. The most cost-efficient is to only apply the required gear and handling routines where it is needed individually for all the lab environments. The most time-efficient way of doing so is to keep the gear in connection to the lab environment. Still, when there is an absolute prohibition for bacteria and goods need to be sprayed with a bactericidal agent before entering, the spraying station should be situated in connection to the inventory instead of the lab environment to enable the workers to do other assignment when the agent is working.

4.3.2 Design parameters

In this section, suggestions for how the design parameters can be set up in a material supply system in the pharmaceutical industry in a research and development plant to achieve a cost-efficient service level are presented. The suggestions are based on the theoretical framework and the empirical data from the case company.

Inventory structure

A material supply system in a research and development plant in the pharmaceutical industry should generally have a centralized inventory structure. According to the theory, an inhouse distribution network, holding relatively small but expensive articles which are transported short distances without incurring any substantial transportation costs, does not justify having more than one inventory (Jonsson & Mattsson, 2016; Lee & Jeong, 2009). In the case company, the current decentralized structure results in many non-value adding activities which decreases the inbound process efficiency (Li et al., 2016). Difficulty in order picking, excess cycle counting and monitoring of deliveries are all resource consuming attributes of the current inventory structure (Chapter 4.2.3). According to Eppen (1979) the total handling cost constitutes the square root of its size, Formula 2. Hence, reducing the number of inventories from 13 to one will decrees the handling costs multiply. Further, the total inventory holding cost is considerably higher with a decentralized structure. At the case company, these costs have not been monitored historically but a majority of it, is believed to be related to obsolescence of articles due to overstocking. With a centralized structure and the existing service level for all individual articles maintained, the tied-up capital in the system would be decreased with 17.4% (Appendix 1 and Figure 18). With an inventory holding interest of 20% and the value in inventory of 4 988 869 SEK, this change alone would result in a hypothetical 173 613 SEK saving per year for the case company.
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Figure 18: Graphical illustration of the value tied up by the current minimum inventory level and the theoretical level with a decentralization with the same service level.

Order point and safety stock

The order point in the inventories should cover the demand during delivery lead-time and incorporate a safety stock to guard against fluctuations (Jonsson & Mattsson, 2016; Alstrøm, 2001). In the pharmaceutical industry in research and development plants, availability of lab supplies has a very high priority (Nematollahi, 2018). In the case company, this is expressed through the high order points, as described in Chapter 4.2.3. Further, the high order points are present on two inventory levels, both in the inventories and the PoU. According to the focus group, this is the usual set up for material supply systems in the context of this study. Therefore, the service level in the inventories can be lowered without risking disruptions because there is a second level of redundancy in the system.

Establishing the order points and ingoing safety stocks can be done using several different methods with varying accuracy and required administrational effort. Some of these are described in Chapter 2.4.2 and 2.4.4. Usually, a mixture of methods is applied in a material supply system to simplify administration. The methods are applied based on a segmentation of the articles, often based on value and demand. The pareto rule is commonly used as a guideline to segment articles (Fichtinger, 2017). In the context of this study, the article assortments in the material supply systems are often wide, which justifies segmentation to enable administration. Also, both the variation in demand and unit value is substantial why they should be interpreted in the classification. At the case company, 80% of the value turned over in the system is represented by 16,6% of all registered articles, or 22,7% of those that were consumed during 2017. These articles generate a higher cost and their order points will therefore be calibrated individually by using the most accurate method, which is also the most resource consuming, presented in Chapter 2.4. The method is obtained by combining Formula 3 and Formula 5, creating a new formula (Jonsson & Mattsson, 2016).

Formula 6: \[ \text{Order point} = \text{Safety stock} (k \times \sigma, \) + Demand \times \text{Lead time} \]

The safety factor \( k \) is set to 90%, but will in practice result in a much higher service level in the system due to the multiple layers of redundancy. Even among these articles which incurs the highest cost, there are several that are consumed in very low volumes which makes the method inept. The formula for safety stock is based on the normal
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distribution curve which is hard to calculate accurately with few readings. For these articles the existing minimum inventory level is kept. The articles are selected if they were consumed less than ten times during 2017 or had an order which affected the standard deviation substantially by being at least 500% over the normal.

The remaining articles in the system have lower demand frequencies in general which makes the above formula otiose. Further, they account for lower costs why a higher service level can be justifiable (Jonsson & Mattsson, 2016). For these articles, the order point will be dimensioned based on demand during lead-time in different intervals where the service level should correspond to at least 90% (Appendix 2). In the case company, dimensioning the order points using these methods, segmentations and service levels would result in a total minimum inventory level of 6 484 units holding a value of 936 011 SEK compared with the current 20 936 units with the value of 1 751 130 SEK (Figure 19).

Figure 19: Graphical illustration of the number of articles with the current minimum inventory level and a hypothetical new minimum inventory level.

**Order quantity**

From an economic standpoint, the order quantity should represent the lowest sum of the ordering cost and the inventory holding cost associated with the order (Chapter 2.4.3). The ordering costs may vary between companies but generally within this industry and business function, contractors are hired with automated ordering systems (Chapter 4.2.3). Therefore, the ordering costs are often relatively low. However, inventory holding costs are often high due to the wide assortment and perishable character of the goods (Nematollahi, 2018). In the following calculations, an administrative cost of 25 SEK per article is added to any other order specific costs associated to the article. The inventory interest is set to 20%. The data from the case company is used as a practical example for how the order quantities could be dimensioned based on Formula 4. The formula was applied to all articles individually in the system and the numbers were rounded to the nearest integer. Then the articles which are delivered in specific packing sizes were rounded to the nearest number of units in a full packing size. Finally, order quantities that were lower than the demand
during the lead-time were rounded up to equal at least the demand during lead-time to make the system easier to manage in practice.

At the case company, the above calculations resulted in substantially lower order quantities than the existing. The sum of all new order quantities was 13 796 units which represents a value of 1 555 466 SEK compared with the existing order quantities which sums up to 28 662 units with a value of 2 616 433 SEK (Figure 20). If paired with the minimum inventory level produced in the previous section, the average total inventory level plantwide would be roughly 13 368 units with a value of 1 713 744 SEK. The current hypothetical average total inventory level is as described in Chapter 4.2.3, 35 263 units representing a value of 3 059 347 SEK. If applying the inventory interest of 20% that difference represents a yearly saving of 269 120 SEK. However, as described in Chapter 4.2.3, the actual inventory level is much higher with 55 175 units in stock with a value of 4 988 869 SEK. One of the causes is that the levels were even higher historically why some articles are left from old orders. The ones that are no longer consumed should be discarded and the other ones will eventually get down to their intended levels. The other cause is that full packing sizes are always ordered to reach the maximum inventory level in the system which, in the event of a shortfall, results in more than the intended being ordered. This should be solved by having a fixed order quantity which is ordered automatically and can be adjusted exceptionally if there is a substantial shortfall. If these changes would be effective and result in the new average inventory level being maintained, the save compared with the existing level and the inventory interest of 20% would be 655 025 SEK per year.

Figure 20: Graphical illustration of the order quantities in units per article with the new calculated order quantity and the existing order quantity at the case company.

4.3.3 System dynamics

In material supply systems in the pharmaceutical industry in research and development plants, the article assortments are wide and the demand is varying and unpredictable (Benner, 2009; Nematollahi, 2018). Therefore, the dimensioning of safety stocks, order points and order quantities cannot be established just once and then stay viable to maintain a cost-efficient service level. The system needs to be dynamic to stock the relevant articles in quantities that are both economically justifiable and that secures a
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desirable service level (Jonsson & Mattsson, 2016). As described earlier, the case company has historically collected high amounts of supplies for different reasons. Decreasing the order quantities and lowering the order points in general according to the changes in Chapter 4.3.2, is a step in the right direction to make the system more agile and prevent that from happening in the future. With lower order quantities, the orders will be placed more frequently which makes it easier to detect changes in consumption patterns. Further, lower order points decrease the risk of stocking high number of units of an article when it eventually seizes to be consumed and needs to be discarded. A centralized inventory structure, as suggested in Chapter 4.3.2, will also enable the system to be more dynamic and agile by consolidating the consumption from all PoU which will result in more frequent orders which are easier to monitor.

With those enabling factors in place, there needs to be routines that can be followed to adjust the levels. To make the levels in the system both agile and well calibrated over time, two separate routines should be conducted. The first should be part of the daily work activities, similar to how the case company has aimed to work with the levels previously. While the workers perform their work activities they should keep in mind if there is something that has changed in the system. If an article starts to run out often, its safety stock should be increased by increasing the order point and, if the order quantity is consumed faster than the lead-time, it should be increased. On the contrary, if the there are many units of an articles left in stock every time a delivery arrives, the safety stock should be decreased by lowering the order point. Further, if the order quantity covers a long time of consumption and has no specific deliver cost, it should be decreased. The second routine should be based on data retrieved from the ERP-system and could be conducted quarterly. The same methods used in Chapter 4.3.2 should then be applied again to the most recent data to calibrate and update the levels in the system. A desired state would be to integrate those methods as algorithms in the business layer of the ERP-system (Mo et al., 2013). Lastly, in the focus group it was discussed that there need to be a routine to phase out articles which are no longer consumed. One participant in the focus group suggested that 180 days should be the limit for how long an article can sit in an inventory without being consumed before being moved out. Follow-up on this should be done in connection to the quarterly routine. Monitoring the consumption rates and moving out articles also enables segmentation of the inventory where the most frequently consumed articles can be placed on the most easily accessible shelf spaces. Thus, the quarterly updates can form the base for an ABC classification of the inventory to enable faster order picking (Fichtinger, 2017; Teunter et al., 2017).

4.3.4 Facilities

The facilities associated to the material supply system can enable the work activities by being effective for the purpose. The inventories themselves should be sufficient in size to accommodate both shelf spaces for all the articles, a place for deliveries, an unpacking station and an area to treat goods that need special handling. At the case company, a spraying station is needed for this matter. Due to the uneven consumption rates of different articles, the inventory could advantageously be segmented with different shelf solutions. The most frequently consumed articles are picked several times every day and should have shelves intended for fast picking with a strategically accessible position in the inventory. The least frequently consumed articles are picked
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just a few times per year and should have shelves intended for space-efficiency with a less accessible position in the inventory.

With a centralized inventory structure, high volumes of deliveries will both be received and delivered from the inventory. This justifies investing in efficient tools and equipment for the purpose. Waste disposal should be easily accessible from the unpacking station and appropriate gear to open and disassemble packages should be in place. An unpacking table with adjustable height would be appropriate in an environment that several workers share. Safety gear to cover eyes and hands should also be in place at the unpacking station. Further, as all deliveries are inhouse, trolleys will be used which should be sufficient to accommodate at least a full order to one PoU. At the case company, the trolleys are currently too small to handle the biggest orders why double deliveries are needed. That is not practical with the current inventory structure and will be even less practical if all deliveries depart from a central inventory. Depending on the worker and the work environment, trolleys that can hold several deliveries to different PoU could be advantageous. The high number of delivery locations and the wide article assortments renders many order lines and frequent picking of articles. At the case company, the picking lists are currently printed but it would be more efficient to use a digital tablet that can generate new, updated picking lists continually by interconnecting the data layer with the presentation layer (Mo et al., 2013).
5 Discussion and conclusions

In this chapter, the execution and result of this study are discussed based on the selected method and the retrieved findings. First, the findings are discussed based on the research gap it aimed to fill. The different aspects of methodological selections are evaluated based on intention and result. Finally, conclusions are drawn regarding the aim and the result of the study and what implications can be made based on the findings.

5.1 Discussion of findings

The purpose of this study was;

to investigate how a material supply system for consumable lab supplies can be improved within a research and development plant within the pharmaceutical industry.

Based on the purpose, two research questions were formulated which if answered should fulfil the purpose.

1. What factors are critical to achieve a cost-efficient service level in a material supply system for consumable lab supplies within a research and development plant in the pharmaceutical industry?

The intention of this research question was to find the factors with substantial effect on cost and service level in material supply systems in the described context. In the theoretical framework, several factors effecting the cost-efficiency and service level were described. Also, formulas were introduced for how the factors: inventory structure, dimensioning of safety stock, order point and order quantity affected cost and service level within material supply systems in general. These formulas had not been tested yet in the context of this study. Instead, research and development plants within the pharmaceutical industry were in the theoretical framework described in general terms with context specific aspects. Therefore, the aim of this study in regard to the first research question, was to bridge the gap between the general design factors for material supply systems and the aspects prevailing in the context of this study. This was done by forming connections between the contextual aspects and the design factors on a hypothetical level that was investigated at the case company for validation or falsification.

Overall, the general design factors for material supply systems where viable in the studied context with the added context specific factors; design purpose, boundaries and system dynamics. However, the general design factors interconnections and relative effect on each other were not emphasized in theory but appeared prominent at the case company. The current inventory structure appeared to be the root cause for many flaws in the system which affected the other factors negatively, and the inability to improve it illustrates the gap in research. The decentralized structure aggravated the difficulty to maintain a cost-efficient service level through several unexpected aspects. Unfortunately, as described in Chapter 5.2, this study was not able to produce precise values for how cost and service level was affected by these aspects but merely stated a negative effect by referring to theoretical principles. However, the research question does not expressly request the exact effect in numbers why merely identifying and demonstrating an effect was regarded sufficient for successfully answering it.
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2. How could a material supply system for consumable lab supplies within a research and development plant be designed to achieve a cost-efficient service level in the pharmaceutical industry?

The intention of the second research question was to, based on the factors identified when answering the first research question, present a design suggestion applicable for material supply systems in the context of this study. To generate a design suggestion, assumptions had to be made regarding costs associated with certain work activities and processes for companies in the context of the study. Further, as described in the previous section, the general design principles and the associated formulas had to be adjusted to suit the specific context of this study.

In theory it is described that the inventory structure can be optimized by finding a balance between transportation cost and inventory holding cost. Initially, these costs were intended to be investigated at the case company. However, the transportation costs quickly appeared to be a small factor in the studied context which had not been considered a substantial advantage when designing the decentralized structure. Further, the difference in inventory holding cost related to inventory structure was in this context overshadowed by other aspects, described in Chapter 4.2.3, which incurred high costs due to process inefficiency related to the decentralized structure. Therefore, the exact effect on cost dependent on inventory structure could not be calculated in this context because the general formulas was inapplicable. However, it could be put beyond all reasonable doubt that a centralized inventory structure was the best alternative to achieve a cost-efficient service level.

For the factors concerning quantities of articles, the general formulas retrieved from theory were applied but required a few assumptions and adjustments to suit the context. Inventory interest was not a term used at the case company but considering the high obsolescence costs, it was assumed to be high and after consultation with the focus group, 20% was established as a reasonable rate. The ordering cost was argued to be very low in the focus group but the observations yielded that it does take some administrative effort for the workers in the system and sometimes the system fails which requires manual work. Therefore, the relatively low but still palpable administrative cost of 25 SEK was added to all order lines. With those assumptions in place, the formulas were applied to calculate safety stocks, ordering points and order quantities for all articles individually in the system. However, the formulas appeared to be developed for material supply systems handling much higher volumes than the material supply systems in the context of this study. When applying them to the articles with lower consumption rates, which represented a majority of all articles, they often appeared blunt and produced strange results. Therefore, the method had to be adjusted but was still based on the underlying theoretical concepts of the formulas when dimensioning the quantities for the remaining articles.

Consequently, the study did generate a material supply system design based on the fundamental design principles with adjustments to suit the context of the study. The new design would in comparison to the existing system design at the case company, operate at a much lower cost. Its effect on the service level was hard to estimate due to insufficient data regarding the second inventory level in the system, namely the PoU. These constitute a large buffer which makes the service level towards scientists considerably higher compared to the one in the inventory. The service level in the
inventory was set at 90% when applying the formulas which means that the effective service level towards the scientists should be close to 100%. Also, the suggested design is much more consistent in relation to the existing which means that the total service level can get higher by simply redistributing the number of units per article. Hence, the second research question is considered successfully answered.

5.2 Discussion of method

A single case study was selected for this study because it was considered the most appropriate for investigating how a material supply system can be improved within the pharmaceutical industry in a research and development plant. The immaturity of the theoretical field implicated that it was desirable to study the phenomena in their real-life context which a case study is a suitable method for. A multiple case study would have been desirable to conduct to increase the validity of the study and reduce the influence on the findings from unique circumstances at the case company. However, the given limited time scope of the study and its specified context which narrowed down the selection of suitable cases to very few, made a single case study the better choice. High focus could be dedicated to the single case which enabled the study to go more into depth. Further, plants within the given context of the study are regulated by strict laws and their internal structure is often similar why the case company is expected to be representative for the studied field and context. Consequently, the result of this study, should be generalizable to other companies within the same context.

The immaturity in the research field and the explorative elements needed for the study, paired with the ambition to apply existing theory to phenomena in their real-life context, made an abductive approach suitable for this case study. Both deductive and inductive approaches were considered as alternatives. However, the immaturity of the research field would have resulted in a deductive approach not having sufficient theoretical data for founding a well substantiated hypothesis. An inductive approach could have been possible to conduct. However, it was dismissed because phenomena described in theory developed within other contexts was to be tested in the context of this study to understand if they were universally applicable. Thus, the findings of the study needed to be of both generalized and hypothesis tested character. The abductive approach proved to be very effective throughout the study as phenomena that was not described in theory appeared at the case company which confirmed the expected gap in research. It allowed the literature review to be extended when new phenomena appeared to include adjacent research fields which had not been reviewed yet for theory matching. Thus, the literature review progressed in parallel with the case study which broadened the theoretical framework and enriched the study.

Before initiating the main study, comprising the majority of the data gathering and study of the phenomena in depth, a pre-study was conducted. In retrospect, the importance of the pre-study cannot be emphasized enough. The direction of the study was clarified and a plan for the process of the study was established which has enabled the study to progress smoothly without any major setbacks. Further, contact was established with key-employees during the convergent interviews. Also, an understanding of the culture, routines and the material supply system at the case company was gained. In hindsight, it could have been preferable to have progressed further with the literature review before visiting the case company the first times. However, the abductive approach
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allowed for the literature review to continue throughout the empirical data gathering which made the early start at the case company possible.

The main study was conducted using four research instruments for collecting empirical data: observations, interviews, focus groups and documents. Initially, interviews and quantitative observations were considered as exclusive research instruments. However, the limited number of workers in the system would result in supposedly too few data points to draw valid conclusions from without backing from other instruments. When being introduced to the work in the material supply system, the article assortment appeared to be wider than expected, spread over the plant and oftentimes handling very low frequencies of consumption. Hence, making a protocol to track consumption rates and clocking work activities plantwide would be a too extensive task for the scope of this study. Instead, the above four instruments were selected to support each other and to triangulate the studied phenomena.

Combining the four instruments functioned well and especially the interviews, observations and the focus groups complimented each other very well. The perception is that more factors affecting the material supply system were identified by using several methods and that they could be better analyzed yielding results with higher validity and reliability. The documents constituted the only quantitative input of the study which makes those evidence less robust. Further, the workers stated that the delivery lead-times for external suppliers must be entered manually in the system by them, which sometimes have not been done perfectly. Meaning that the lead-time found in the documents may sometimes be inaccurate. However, these factors were managed by letting the interviews and the participants in the focus groups comment on the trustworthiness of the data and if necessary adjust it. Also, the data from the documents was audited and tested more severely which have increased the reliability of the result.

To fully understand the effect of suggested changes in the inventory structure at the case company based on the identified factors, work sampling would have been an effective method to test the current and hypothetical future state. However, as stated previously, the variety in work activities and the extent and width of the system made such an instrument too resource demanding for the scope of this study.

5.3 Conclusions

The aim of this study was to investigate the research gap regarding material supply systems for lab supplies in research and development plants in the pharmaceutical industry. Material supply systems in general, have for a long time been a function gaining strong attention. Its cost saving potential and ability to generate competitive advantages by providing a high service level with agile responsiveness for articles and components, have been a proven success factor in different industries and business functions. However, not yet in the context of this study. Hence, this research endeavor has sought to fill the research gap concerning material supply systems in the specified context. By utilizing the existing general research on material supply system and adapting it to the specific context of the study.

The empirical findings demonstrated that material supply systems in research and development plants in the pharmaceutical industry comprise factors that the general design principles are not developed to account for. The varying and commonly very low consumption rates, the uncertainty of future consumption and the wide article
assortment were factors identified and connected to the context. These must be accounted for and merged with the general design principles to create an effective design. However, the general design principles with formulas for how to dimension safety stocks, order points and order quantities could advantageously be used as the foundation in the context of this study too. Further, the underlying theoretical principles which the formulas are based upon were utilized when establishing methods which accounted for the context specific factors. At the case company, initial attempts had been conducted to increase the cost-efficiency in relation to service level. However, those endeavors had been poorly supported by research and generated varying results why this study was welcomed. Applying the design suggestions generated by the study to the case company would result in substantial cost savings with a more consistent service level at a continually high level.

The practical implications of this study are explicit for the case company in particular and other companies in the same and similar contexts in general. The critical factors identified for material supply systems in the specified context provides a good starting point for companies to evaluate their organizations and base or calibrate their material supply system design on. Further, the presented design suggestion can be applied to design a material supply system in full, or in segments to calibrate certain aspects of the system. Thus, the study implicates guidelines for how a material supply system can be designed to achieve a cost-efficient service level in research and development plants in the pharmaceutical industry. The case company has audited the result of the study and considers the presented critical factors as relevant and the design suggestions as well suited for their organization. An implementation project has therefore been initiated where the author of this report participates. The project aims to reduce the number of inventories from 13 to 1 by closing one at a time and in parallel expand the largest existing inventory to accommodate all deliveries. The minimum and maximum inventory levels will be altered in accordance with the calculated suggestions in this report, but updated from the year of 2017 to the latest six months, from May 14th, 2018.

The study has also resulted in theoretical implications to the associated research field. As emphasized previously in the report, there has been a gap in research regarding material supply system design in the pharmaceutical industry in research and development plants. This study fills that gap by concluding which factors are critical to achieve a cost-efficient service level in material supply systems in the specified context. Further it suggests how the existing, general design principles can be adapted to suit the context of the study. Thus, it concludes how, and based on what critical factors a material supply system can be designed in the pharmaceutical industry in research and development plants to achieve a cost-efficient service level. It also proves that the general design principles are quite universal and can be adapted to suit other contexts than they primarily where designed for.

Further, studies could investigate if the context specific factors identified in this study are relevant in other contexts too and how they can be further refined. The existing methods for designing material supply systems are focused on high volume articles with relatively stable demand. Articles with low and varying demands are not compatible with these methods why further research is needed on how these can be managed cost-efficiently with a high service level. Also, research on how the service level is affected in practice by having more than one inventory level for the same articles on plant would be an interesting topic for further research.
References


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6 Appendices

6.1 Appendix 1: Savings from a reduced number of inventories
The relation between number of inventories and inventory holding cost is due to the lower total amount of inventory required to maintain a given service level with fewer inventories. In Chapter 2.4.1, Formula 1 was introduced. Because the articles are present in various numbers of inventories, the savings share had to be calculated for all articles individually. It was then multiplied with the established minimum inventory level and the unit cost for each article. When adding the minimum inventory levels for all articles in all inventories, their total value amounts to 1 751 131 SEK. A hypothetical total minimum inventory level for an inventory structure with one inventory was calculated by applying the formula and for all articles. The total value for all articles minimum inventory levels would then amount to 1 446 373 SEK.

6.2 Appendix 2: Demand during delivery lead-time intervals and their order points

| Demand during delivery lead-time intervals and their assigned order point |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| ≤ 0,06 = 0                 | ≤ 0,276 = 1                | ≤ 0,54 = 2                  | ≤ 0,83 = 3                  |
| ≤ 0,822 = 4                | ≤ 1,044 = 5                | ≤ 1,248 = 6                 | ≤ 1,812 = 7                 |
| ≤ 2,052 = 8                | ≤ 2,448 = 10               | ≤ 3,762 = 12                | ≤ 4,074 = 15                |
| ≤ 6,3 = 20                 | ≤ 10,98 = 30               | ≤ 14,738 = 40               | ≤ 20,736 = 50               |
| ≤ 36,744 = 60              | ≤ 48,6 = 70                | ≤ 95,28 = 183               | ≤ 116,79 = 200              |