The Effects of an Increased Traceability on Lead Times

A case study on a material replenishment system at a Swedish industrial tools manufacturer

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Master of Science Thesis
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Effekten av en ökad spårbarhet på ledtider

En fallstudie av materialförsörjningen på en svensk tillverkare av industriverktyg

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Abstract

This study investigates the relationship between an increased traceability and shortened lead times in the internal material replenishment system at a large Swedish industrial tools manufacturer. Traceability and its effects on uncertainty in the supply chain has been widely researched in academia, but there is a gap regarding how traceability affects lead times.

The research investigates which factors drive the lead times in the material replenishment to lean assembly lines and determines how these factors relate to traceability. A case study was conducted in one of the case company’s factories. The study consists of both quantitative and qualitative data. The quantitative data was derived from the case company’s ERP-system while the qualitative data consists of interviews and empirically collected data.

The results of the study show that waiting time is the primary driver of lead times in the current state of the factory. No indication that internal material replenishment lead times decrease as a result of an increased traceability was found. However, there are aspects with an increased traceability that indirectly facilitates reduction of lead times by making it easier to make well-informed decisions due to the increased availability of real-time data.

Traceability is found to not contribute any value to the end customer on its own. However, it can play an important role in a company’s supply chain. Further, potential advantages with a high traceability were observed when implementing advanced protocols such as JIT and other lean principles. The study should be seen as a starting point to further studies into the relationship between increasing traceability and reduced internal lead times.

For managers and companies, the study identifies a potential procedure to use for determining which factors drive replenishment lead times to lean assembly lines. Furthermore, the study shows that companies can have great use for traceability when trying to remove waste from its processes.

Key terms: Traceability, Lean Manufacturing, Material Replenishment, Internal Lead Times, Continuous Improvement
Sammanfattning

Denna rapport utreder sambandet mellan en ökad spårbarhet i den interna materialtillförseln hos ett stort svenskt producenterande företag och minskningen av dess ledtider. Forskning har bedrivits inom spårbarhet och kring dess effekter på osäkerheten i en supply chain, men det finns begränsad forskning gällande spårbarhetens effekter på interna ledtider.

I studien undersöks vilka faktorer som driver ledtiderna i materialtillförseln till lean monteringslinor hos ett producenterande företag och hur en ökad spårbarhet påverkar dessa. En fallstudie har utförts hos ett industriföretag, i en av deras fabriker. Studien använder sig av både kvantitativ och kvalitativ data. Den kvantitativa datan kommer från fallstudieföretagets affärsystem medan den kvalitativa delen består av intervjudata och empiriskt genererad data.

Resultatet av denna studie visar att det främst är väntetider som driver upp ledtiderna i fabriken. Inga bevis hittades för att interna materialtillförselns ledtider minskar som en direkt följd av en ökad spårbarhet. Däremot finns det aspekter med en ökad spårbarhet som hjälper att minska ledtiderna indirekt genom att underlätta för bättre underbyggda beslut som följd av en ökad tillgänglighet av data i realtid.

Denna studie visar på att spårbarheten i sig inte skapar något värde för slutkunden, men att det trots det kan spela en viktig roll i företagets supply chain. Dessutom påvisas potentiella fördelar med en god spårbarhet när man implementerar avancerade system så som JIT och andra lean-principer. Rapporten bör ses som en startpunkt för framtida studier för att undersöka sambandet mellan en ökad spårbarhet och minskade ledtider.

För företag så innebär denna rapport en möjlighet till att få en förståelse för vilka faktorer som driver upp ledtiderna i materialtillförseln till lean monteringslinor. Dessutom visar studien på att företag kan gynnas av att öka sin spårbarhet när det gäller processförbättringar.

Nyckelord: Spårbarhet, Lean Manufacturing, Materialtillförsel, Interna Ledtider, Ständiga Förbättringar
Foreword

The following study was written and conducted for the department of Industrial Engineering and Management at KTH (the Royal Institute of Technology) in Stockholm, Sweden. The study constituted the main part of a 30 credit university course conducted during the spring term of 2015.

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Firstly, we would like to extend a thank you to our supervisor at KTH, Associate Professor Dr. Jannis Angelis. We appreciate all the help with structuring the research process and for getting us unstuck when we inevitably got stuck.

Secondly, we extend our gratitude to the case company, specifically to our supervisor at the case company, to our supervisory manager, and everyone else that has been kind enough to lend their time to our research. We hope the results of the research prove interesting and educational.

Lastly, we would like to thank our families and friends for their continuous, unwavering support and enthusiasm throughout the process.

Stockholm, June 2015

Tobias Hespe and Per Åström
## Nomenclature

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<tr>
<td>AIDC</td>
<td>Automatic Identification and Data Capture</td>
</tr>
<tr>
<td>BOM</td>
<td>Bill of Materials</td>
</tr>
<tr>
<td>CIM</td>
<td>Computer Integrated Manufacturing</td>
</tr>
<tr>
<td>ERP</td>
<td>Enterprise Resource Planning</td>
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<td>FIFO</td>
<td>First In First Out</td>
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<tr>
<td>JIT</td>
<td>Just-In-Time</td>
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<td>LM</td>
<td>Lean Manufacturing</td>
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<td>TPS</td>
<td>Toyota Production System</td>
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Chapter 1

Introduction

*The introduction chapter presents the background to the research problem along with the specific problem facing the case object. The research’s purpose, research questions, delimitations and proposed contribution are also stated and explained.*

1.1 Problem Background

The study investigated how an increased traceability affected material replenishment lead times, defined in this study as the time from start to finish of an internal logistics order, to lean assembly lines.

For many businesses with assembly operations in high-cost countries, the writing has been on the wall since the early 2000s; improve and modernize or get left behind. Development of new technology has proven slow and resource-intensive amidst the ever increasing threat of globalization (Onori et al., 2002; Dabhikar, 2006). These threats include outsourcing, miniaturization (the trend of making products smaller), and more process specific issues (Onori et al., 2002) but can be summarized as an increasing competitiveness in the international marketplace.

Naturally, a central issue for producing companies that assemble their own products has been to identify ways to improve and reinvent their processes (Onori and Oliveira, 2010). Many looked and continue to look to Toyota’s internally developed Toyota Production System (TPS), or more commonly referred to simply as Lean Manufacturing (LM) (Liker, 2004), with the hope of reducing waste in the process.

LM research has recently shifted towards the implementation of the paradigm throughout the organization, ranging from production to administration (Hines et al., 2004). Taking steps to implement LM on a organizational-wide basis requires a rethink of the decision-making process and new ways to collect and analyze data. One way to facilitate this change and allow for the implementation of more advanced tools such as Just-In-Time (JIT) manufacturing is increased visibility and traceability in the organization (Dai et al., 2012).

Increasing the traceability, defined in this study as knowing the location and stock balance of items using computer based systems, in an organization has been observed to reduce processing errors and help stamp out quality issues in a factory’s logistics setup (Fang et al., 2013; Dai et al., 2012). There is also limited evidence that traceability allows for better-informed decisions to be made, due to the increased availability of real-time data.
(Fang et al., 2013; Dai et al., 2012). That being said, low traceability could have the opposite effect and hinder the success of a company’s improvement work simply because the improvement effort might be misplaced. Therefore, it is in the companies’ interest to understand the importance of traceability in their daily operations.

1.2 Problem Formulation

As the competitive landscape changes, companies are forced to adapt. In the face of this ever-increasing competitiveness, emphasis is placed on Just-In-Time (JIT) deliveries and lead time reduction in an attempt to cut inventory and costs (Tummala et al., 2006). There is a need to understand the drivers of lead time to make well-informed decisions based on an accurate analysis of a company’s processes and their current state.

Traceability is a buzzword in supply chain research that has been evaluated thoroughly for the past decade. There is academic research on how traceability affects supply chain visibility and uncertainty (Fang et al., 2013; Dai et al., 2012; Nambiar, 2010). However, research on how traceability affects material replenishment lead times is limited. There could be an opportunity for manufacturing companies and factories to use traceability as a tool for cutting internal lead times, but the relationship between the two factors remains unclear.

1.3 The Case Object

The case study was based on a Swedish manufacturer of industrial tools and the material replenishment logistics at one of their factories. The factory produces a wide range of hand-held and fixed assembly tools. The tools are sold to a range of customers within primarily the automotive and aerospace industries. The factory can be divided into production and assembly and their respective support functions. Assembly workers work between 06.50 in the morning to 15.50 in the afternoon but further afternoon shifts can be added if sales surpass prognoses.

The company works actively on achieving sustainable productivity throughout the organization. This means attaining productivity through taking responsibility for the company’s environmental footprint, by adhering to and promoting human rights, and by doing things in accordance to what the firm considers the "right way."

The case object is in the process of implementing Lean Manufacturing (LM) in both its production and assembly operations. An illustrative example is the conversion of functional assembly groups into lean lines with fixed flow and tact times. However, the cumbersome nature of the case object’s material replenishment to assembly lines was and is driving costs, locking up floor space, and leading to inventory errors.

Managers at the case object were aware of the problems, and the general consensus was that improvements made in the assembly operation was causing a distinct need to reduce lead times for replenishment of components and to address the complexity and confusion regarding internal logistics. There was a lack of visibility and traceability for components but it was unknown how this was contributing to the lead times.
1.4 Purpose and Aim

The purpose of this research was to better understand the interdependency between traceability and lead times within a material replenishment system. This was attempted through a case study, where important factors of material replenishment lead times and the effects of traceability were investigated.

The aim was to support the case company with their improvement work to decrease material replenishment lead times. This was done through an investigation of their current state and a study on how the company could decrease their lead times through increased traceability.

1.5 Research Questions

In order to determine how increased traceability affects the inventory replenishment lead times, a main research question was devised and split into sub questions. The main question was:

**Main Research Question:** How does increased traceability within the material replenishment system to multi-product lean assembly lines affect the internal logistics lead times?

The question was answered by addressing three sub-questions. First of all, the current state of the case object’s material replenishment setup at the start of the study was understood and mapped. Understanding the current state included understanding all processes currently used in the factory, along with problems and areas of improvement. This understanding was pursued by answering the following question:

**Sub question 1:** What is the current state of the material replenishment system?

Secondly, the complexity of the internal lead times and their causes were investigated by addressing the question:

**Sub question 2:** What factors are driving material replenishment lead times?

Finally, the effects of an increased traceability within the system was analyzed by answering the question:

**Sub question 3:** How does traceability affect the material replenishment system?

The main research question itself was not directly addressed. Instead, by addressing the three sub questions, an answer to the main research question of this paper could be derived.

1.6 Delimitations

In order to reach a manageable scope for this research with regards to the study’s limited time frame and the requirements of both the Royal Institute of Technology (KTH) and the case object, the following delimitations were made.
The first delimitation was that the study only focused on the internal material replenishment from the time that the parts enter the factory. This implied that the supply chain outside of the factory, meaning from the suppliers to the case company and vice versa was ignored. This was done since it was easier to control and evaluate the internal supply chain for the purposes of this study.

Further, this research paper investigated the material replenishment stream from external suppliers delivering components to the factory and their subsequent delivery to the lean assembly lines. This delimitation created a more manageable scope, and facilitated a more in depth focus on the internal logistics.

The study focused on material replenishment solely to lean assembly lines. Limiting the research to one specific type of assembly allowed for a more detailed understanding of the specific requirements on the corresponding support functions.

1.7 Proposed Contribution

Regarding the academic contribution, research about the use of traceability in logistics focuses on outbound logistics and logistics associated with the whole supply chain (Chan and Tang, 2007). There are multiple articles on traceability within the supply chain and how this influences inventory. This paper investigated how traceability within inventory replenishment influenced the internal logistics lead times of a producing company. The contribution of the research was divided into theoretical and managerial aspects.

Theoretical: The proposed theoretical contribution was within Computer Integrated Manufacturing (CIM) and concerns how lead times of a material replenishment system are affected by an increase of traceability within the system.

Managerial: The managerial contribution was to provide data and a basis for future operational changes to decrease material replenishment lead times and reduce waste in the internal logistics processes.
Chapter 2

Literature Review

This chapter presents a theoretical framework later used to answer the stated research questions. Four primary topics, LM context, inventory replenishment, shortening lead times and traceability are presented along with subsections containing theory relevant to each respective section.

2.1 Lean Manufacturing Context

This case study investigated the effects of increased traceability on material replenishment lead times to lean assembly lines. Therefore it was essential to first understand the context and key parts of lean assembly lines.

LM is a collective term oftentimes used to describe a framework "that many companies focus on for continuous improvement of processes" (Green et al., 2010; Hines et al., 2004; Petersson et al., 2010). Crucially, LM focuses on the removal of waste that does not add value to the end customer and to continuously strive to identify deviations in processes that can be improved upon (Green et al., 2010; Petersson et al., 2010; Liker, 2004). Hines et al. (2004) assert that deviations and waste exist throughout an entire business system, in processes ranging from manufacturing and logistics to administrative work and day-to-day strategic operations.

Green et al. (2010) propose that the "best practice of lean manufacturing implementations is to approach the event slowly by implementing in a single pilot cell and then continue to spread to other areas of the organization." This is also the standard procedure for implementing LM according to the AberdeenGroup (2006)'s survey of 308 manufacturers, where 90% reported a commitment to LM but findings showed that only 10% had adopted a widespread approach throughout their organizations.

2.1.1 Key Concepts

In order to grasp the context of LM, several key concepts need to be understood. LM is perhaps best known for its different tools and models. These include "cellular manufacturing (CM), one-piece flow, visual control, kaizen, kanban, production smoothing (Heijunka), workplace organization (5S), autonomation and Value Stream Mapping (VSM)" (Esfandyari et al., 2011; Hines et al., 2004).
Most of these concepts and tools have been extensively evaluated in literature, with Hines et al. (2004) concluding that it is the "customer-centred strategic thinking" of LM that is applicable everywhere, whereas shop-floor tools are not. Similarly, Domingo et al. (2007) state that "every factory is different and needs to adapt these tools to its particular manufacturing characteristics, layout, inventory, flow charts, and organization." This has led to a confusion as to how LM tools should be used and applied (Hines et al., 2004).

2.1.2 Wastes According to Lean Theory

As previously mentioned, a vital part of LM consists of identifying and eliminating waste as well as striving towards continuous improvement (Green et al., 2010; Hines et al., 2004; Petersson et al., 2010). The wastes can be present throughout the entire business and come in different shapes and forms (Hines et al., 2004). According to Petersson et al. (2010); Ramesh and Kodal (2012); Chakravorty (2010); Hicks (2007) there are seven main forms of wastes, and sometimes an extra eighth is added. These are:

1. Overproduction
2. Waiting
3. Transport
4. Inappropriate processing
5. Inventory
6. Motion
7. Producing defective products
8. Untapped competence

Ramesh and Kodal (2012); Hicks (2007) describe overproduction as producing more than necessary and hence creating a waste. The ideal would be to create what is needed when it is needed and thus satisfy customer demand (Ramesh and Kodal, 2012).

Waiting is defined as the time spent waiting for the necessary conditions to produce (Petersson et al., 2010). The authors state that this is a common form of waste present in organisations. Hicks (2007) echoes this and also describes it as queuing due to inactivity in a process downstream.

According to Petersson et al. (2010), transport is not a value adding operation. Hicks (2007) describes this waste as unnecessary movement of products that only add time to the overall process.

Inappropriate processing is described as performing more work than what the customer is prepared to pay for (Petersson et al., 2010). Hicks (2007) supports this description, but also adds extra work due to defects, overproduction or excessive inventory to the definition.

Petersson et al. (2010) claim that large storage space, buffers and inventories are often needed to cover for inaccuracy in the delivery process both internally and externally. The waste of inventory can be said to consist of inventory that exceeds the necessary levels to
satisfy the customer needs (Hicks, 2007). Furthermore Hicks (2007) claims that inventory can increase the need for further handling, space and processing.

Hicks (2007) explains the waste of motion as "the extra steps taken by employees and equipment to accommodate inefficient layouts, defects, reprocessing, overproduction or excess inventory". This is echoed by Petersson et al. (2010) as they exemplify non-value adding motion as having to walk to fetch tools. Creating defective products forces rework (Petersson et al., 2010). Hicks (2007) describes this waste somewhat differently and instead mentions the aspect of customer dissatisfaction due to defect products.

Petersson et al. (2010) describe the additional eighth waste as the waste of untapped competence. This implies that there is a risk of not using the full competence of the workforce and causes an overhanging risk of losing employees as well as missing out on potential improvements.

2.1.3 Lean Assembly

Liua and Zuo (2012) define lean assembly as "eliminating all wastes in the assembly process through certain management tools and technologies." The authors identify zero inventory, high flexibility, and zero defects as the three key sub-goals of Lean Assembly.

Domingo et al. (2007) stress that "material handling systems must contribute to synchronous materials flow" in LM. There are several frameworks considered central to achieving Lean Assembly by Liua and Zuo (2012); Domingo et al. (2007); Green et al. (2010). These include line balancing, takted flows, pull and kanban triggers, mixed-model scheduling, and assembly cells. These concepts have together lead to measurable performance improvements that in turn have put an emphasis on reducing component replenishment lead times in a bid to reduce inventories; "the root of all evil" according to Liua and Zuo (2012).

According to Kilic and Durmusoglu (2012), the feeding system plays an important role for the entire manufacturing system. There are two main feeding methods to lean assembly lines: kitting and side stocking (Hua and Johnson, 2010; Kilic and Durmusoglu, 2012). Kitting implies that components are collected from storage locations, prepared if necessary and placed in containers as kits prior to delivering to the assembly line. For side stocking, the components are kept next to the assembly line itself and replenished according to a pre-selected system (Hua and Johnson, 2010).

2.1.4 Processes as Internal Customers

LM places significant focus on the customer; adding value to an organization’s customers should be the basis for improvement work (Hines et al., 2004; Petersson et al., 2010). A customer can be internal or external (Hauser et al., 1996), where an internal customer can be seen as the subsequent step in the value chain whereas the external customer is the end customer.
According to Pfau et al. (1991), an organization’s ability to meet its external customers’ needs "depends directly on how well it satisfies the needs of their internal customer." Both Pfau et al. (1991) and Hauser et al. (1996) argue that there is a direct correlation between providing excellent service to its internal customers and having highly satisfied external customers. Having said that, Pfau et al. (1991) also highlights the flip side as being "just as telling." For instance, a company delivering excellent products or services to external customers but that neglect their internal customers usually suffer from "wasted time, extra quality control costs, and wasted dollars that translate directly to the bottom line."

Pfau et al. (1991) identify a few critical issues that have to be understood in order to offer a high level of service to an internal customer.

1. Recognizing who the internal customer is
2. Understanding the customer’s needs and expectations
3. Understanding the extent to which the needs of the internal customers’ are being met.

### 2.2 Inventory Replenishment

According to Green et al. (2010) material handling is often defined as the moving of material, but the authors classify this definition as too simple. Instead, material handling includes the flow, movement and storage of materials, information, and people in a manufacturing process (Green et al., 2010; Myers and Stephens, 2000). Material handling alone has been known to amount to "more than one-half of the total cost of manufacturing" (Green et al., 2010). It is not considered a value-adding function, even if it is an unavoidable one, meaning that firms often view material handling as a source of competitive advantage if it can be made more efficient (Myers and Stephens, 2000).

Material replenishment can be seen as a subcategory to inventory replenishment. The goal is to replenish the "right material to the right place, at the right time, in the right amount, in sequence, and in the right position or condition to minimize production costs" (Myers and Stephens, 2000). The difference is that whilst inventory handling deals with all material, flow, and storage, material replenishment deals exclusively with the movement, flow, and storage associated with ensuring that the necessary components for production are readily available. This distinction has been made in this study to exclude movements not deemed relevant to the internal replenishment lead times. By looking exclusively at replenishment, the lead time to the internal customer can be documented.

According to Green et al. (2010); Petersson et al. (2010) movement in material replenishment can be the movement of goods from check-in to buffers, from buffers to warehouses, and from warehouses to assembly lines. Flow includes information, components or parts, and people (Green et al., 2010). Storage entails all instances where inventory is held, and includes all issues affecting warehousing. These can include centralized versus decentralized warehousing, different picking policies, floating or fixed warehouse placements, safety stock levels, size, and physical location (Green et al., 2010; Kovács, 2011; Chackelson et al., 2013).
2.2.1 Strategic Decisions

Inventory Management is a widely explored area (Green et al., 2010; Strack and Pochet, 2010; Hua and Johnson, 2010; Skintzi et al., 2008). Depending on the industry and type of business there are many different studies exploring ways to increase efficiency and reduce costs. Strack and Pochet (2010) stress that these decisions have to be taken pyramidal, where strategic decisions set boundaries for tactical and operational decisions. Strack and Pochet (2010) and van den Berg and Zijm (1999) claim that the strategic decisions can be divided into two categories; warehousing and inventory strategy.

Warehousing Strategy

According to Kovács (2011), "the storage assignment problem involves the placement of a set of items in a warehouse in such a way that some performance measure is optimal". Strack and Pochet (2010) additionally state that one aspect of warehousing strategy is the decision of where to place units. According to Kovács (2011), there are two main categories of storage strategies that are commonly used to approach this problem. Kovács (2011) call them dedicated and shared strategies, whilst Grosse and Glock (2014) call them random and fixed storage. They are described as being identical, but given different names in literature. Kovács (2011)’s denomination is used in this study. Kovács (2011); van den Berg and Zijm (1999) introduce a third storage strategy, namely class-based storage, as an important subcategory to shared strategies. These three storage strategies are described in greater detail below and can be seen in Figure 2.1.

Dedicated Storage implies that "specific storage locations are assigned to each item to be stored" (Lee and Elsayed, 2005), meaning that items are always stored in the same slot (Kovács, 2011). Usually, certain item characteristics such as "demand frequency, part number sequence or demand correlations" (Grosse and Glock, 2014) affect the assignment of items according to Frazelle (2002); Glock and Grosse (2012). For instance, the slot assigned to a specific item can vary according to turnover rate or Cube-per-order index (COI) to minimize the average picking time or transport time (Kovács, 2011; Heskett, 1963). Both policies sort the items "by increasing COI, i.e. the ratio of the stock volume to the demand rate, and then places them sequentially to the closest free slots to the entrance" (Kovács, 2011). This is also known as Full-Turnover Storage (de Koster et al., 2007), a popular decision criterion according to Gagliardi et al. (2008).

Lee and Elsayed (2005) stress that one advantage with dedicated storage is that the data-handling process is made more efficient. Montulet et al. (1998) adds the possibility to minimize the peak load of the system as another advantage. The peak load is described as "the maximum value of the daily loads over a fixed planning horizon" (Montulet et al., 1998). Another advantage is the potential gains in handling high-demand articles in lean manufacturing (Chen et al., 2013). The authors argue that by positioning the articles close to the entrance and departure points the average storage and picking time can be reduced for high-demand items. Further, workers become more familiar with product locations according to Chackelson et al. (2013).

However, space utilization tends to be low (Chackelson et al., 2013). This is a result of having locations reserved solely for specific items and because the total warehouse size
needs to be sufficiently sized in order to store maximum inventory levels for each article if required, for instance during peaks in demand.

**Shared Storage** is described as parts not having pre-determined storage locations. It is synonymous with random storage (Grosse and Glock, 2014; Chackelson et al., 2013) and is better suited if storage levels vary over times due to a lack of reliable data on item demand according to Kovács (2011); Tompkins et al. (2010). Goetschalckx and Ratliff (1990) state that shared storage allows for a more flexible use of storage space, but that it requires a more complicated data-handling system. Chackelson et al. (2013); Tompkins et al. (2010); Grosse and Glock (2014) argue that space utilization is high at the expense of travel distance and product identification. The authors describe both as being significantly more time-consuming and complicated.

Closest Open Location Storage is a variant of Shared Storage. This strategy entails letting workers in the goods check-in choose the "first free location" (Chackelson et al., 2013) to store the items. Hence, locations closer to the depot are normally utilized more often than those further away. The lone characteristic to consider here is the physical location of warehouse storage slots, so whereas the selection criteria is not entirely random, the strategy falls under the category of Shared Storage.

**Class-based Storage** as described by van den Berg and Zijm (1999) implies that products are grouped based on demand rates and that these groups have pre-determined zones where they are stored. Both de Koster et al. (2007); Chackelson et al. (2013) see Class-based Storage as a combination of Dedicated and Shared Storage. Items are clustered so that the "fastest-moving class contains about 15% of the products stored, but constitute about 80% of the turnover (Chackelson et al., 2013). Each item class is assigned to a "dedicated zone" within which items are stored at random (Bottani et al., 2012). The authors state that fast-moving items can be grouped as A-items, with the subsequently fastest-moving categories grouped as B-items and so forth.

The result is that a Class-based Storage requires more space than a simpler, random storage strategy. However, the advantages include a marked reduction in travel time (Chackelson et al., 2013), and an ability to store a high number of items efficiently according to Grosse and Glock (2014).
CHAPTER 2. LITERATURE REVIEW

Figure 2.1: Examples of common storage policies as illustrated by Chackelson et al. (2013)

Inventory Strategy

In addition to the selection of storage strategy, inventory levels also have to be understood. Nenes et al. (2010) stress the importance of Inventory Management on the overall performance. Furthermore, the authors discuss the common trade-off between high holding costs and obsolescence in the inventory and low service due to stock shortages.

There are models that can support the inventory policies of a firm, such as the Economic Order Quantity (EOQ) (Borgonovo and Peccati, 2007; Nenes et al., 2010). The area of EOQ is well-researched and multiple extensions to the original theory have been proposed (Chang, 2004; Papachristos and Konstantaras, 2006; Khan et al., 2011). The objective of the EOQ model is "to minimize the average total inventory costs over an infinite time horizon" (Yu, 1997). The classical EOQ model investigates one product and under the following parameters (Yu, 1997):

- Demand is known and fixed at $d$ units per unit of time.
- There is a fixed order cost $K$ and a known holding cost $h$.
- Stock-outs are not allowed, lead time is instantaneous and there is no time dis-
counting of money. This eventually results in the equation $Q^* = \sqrt{\frac{2Kd}{h}}$. Various relaxations of the above parameters has resulted in extensions of the EOQ model that attempt to describe more realistic scenarios (Khan et al., 2011; Papachristos and Konstantaras, 2006; Chang, 2004). For example Papachristos and Konstantaras (2006) and Khan et al. (2011) have investigated the effects of imperfect quality on the EOQ model. Other extensions as mentioned by Zhang et al. (2011) include partial backlogging and correlated demand.

Reordering Strategy and Kanban

The reordering strategy of an inbound logistics set-up is a key component of the inventory strategy. According to Rahman et al. (2013) it incorporates both strategic and day-to-day aspects of how a refill order is made. Kanban literally means "visible record" or "visible part" (Surendra et al., 1999; Rahman et al., 2013). The term usually refers to a signal, either digital or in the form of physical Kanban cards, that triggers the process of a customer pulling a part in demand from the supplier (Rahman et al., 2013). The customer can be external or internal, in accordance with section 2.1.4. Kanban is generally used as a tool to achieve JIT delivery of parts, ensuring cost savings through the elimination of overproduction, reduction of waste, minimization of waiting time and costs associated with logistics, and the general reduction of waiting times and logistics costs according to Rahman et al. (2013); Surendra et al. (1999).

Picking Strategy

According to Strack and Pochet (2010), "the order picking activity represents 65% of the total cost and 50% of the workforce of a warehouse". It is a paramount part of the strategic decision and therefore both order batching and order routing decisions are discussed below.

Chackelson et al. (2013) claim that there are two main batching strategies: picking by order and picking by article. Order batching helps "utilize the carrying capacity of the order picker by consolidating or splitting individual orders, which can reduce travel time" (Grosse and Glock, 2014; Henn et al., 2012).

Picking by order is described as a policy where the picker completes a picking tour to collect all articles for a specific order (Petersen and Aase, 2004; Chackelson et al., 2013). This policy is often preferred, because of the ease to implement it and since the order integrity is always maintained according to Petersen and Aase (2004). Picking by article on the other hand is described as multiple articles being grouped together to a batch and then picked by the picker (de Koster et al., 2007). By doing this, the picking productivity can be increased by picking in a unique tour according to de Koster et al. (2007).

In addition to batching strategies, routing is also a part of the picking strategy. According to Chackelson et al. (2013), this can be described as the specific sequence in which orders are picked during a tour. Roodbergen and de Koster (2001) stress the possibility of reducing the picking force and thereby lowering the connected costs by making more
efficient picking routes. According to Petersen and Aase (2004), this is done by minimizing the distance travelled by the picker. Multiple theories and models have been developed to aid managers in identifying these optimal picking routes (Petersen and Schmenner, 1999). Further, there has been a recent peak in research regarding different aids for pickers, such as visual or other sensory prompts (Reif and Günthner, 2009). For example, Reif and Günthner (2009)’s study on different order picking technologies such as scanning, pick-by-light and a state of the art "pick-by-vision" system using augmented reality resulted in the conclusion that "the users are faster and make fewer errors."

2.2.2 Inventory Discrepancy

An inventory discrepancy is defined in literature as the "difference between actual inventory and inventory records" (Lee and Özer, 2007) and is often referred to as Inventory Record Inaccuracy (IDI) (DeHoratius and Raman, 2008). DeHoratius and Raman (2008) use the example of an automated replenishment system where an order is sent when the quantity of a certain article in stock reaches a pre-determined level. They present the argument that "if the recorded inventory quantity does not match the quantity present on the store shelf, this system either order when an order is unnecessary or fail to order when it should."

Discrepancies have been observed to arise in a number of different situations (Lee and Özer, 2007; DeHoratius and Raman, 2008). DeHoratius and Raman (2008) investigated inventory discrepancies at a retail organization in their study. For example, discrepancies were found to occur when items were moved physically throughout the supply chain on numerous occasions. Discrepancies were also found to be a result of "restocking or replenishment errors, database errors, poor or incomplete data synchronization, and counting errors."

In DeHoratius and Raman (2008)’s study, replenishment errors arose when store employees did not scan each delivered item to the store when they were received. Instead, assumptions were made regarding the actual delivered quantity per pallet or case and that quantity was entered. Database errors could be mismatches between the recorded and actual inventory due to a lack of synchronization or time lags. Manual inventory counts were also observed as problematic, due to the high occurrence of manual counting errors and a lack of interest.

2.3 Shortening Lead Times

Shortening the time it takes for a customer order being placed to the customer receiving the ordered items has the potential to be "a source of competitiveness" (de Treville et al., 2014). However, there are numerous studies that conclude that companies find it difficult to reduce their lead times and to quantify the effects of reducing lead time on the performance of their business (Fisher, 1997; de Treville et al., 2014).  
de Treville et al. (2014) claim that shortened lead times help reduce "demand-risk exposure" by bringing supply closer to demand. Further, shortened lead times allow for the "order decision to be made based on an updated demand forecast" (de Treville et al.,
The authors argue that the value of shortened lead times decreases if firms have "other alternatives to obtain demand information." Bellamy et al. (2014) identify information sharing as a means of achieving shorter lead times, mainly through faster and cheaper order processing. Hence, literature outlines a relationship between information sharing and lead time, and between lead times and ease of forecasting.

Additionally, Sheu and Wacker (1997) investigated the relationship between part commonality as well as system complexity and lead times. The conclusion was that complexity drives lead times; higher parts commonality and lower system complexity help reduce the lead time. There is a general agreement in literature that complexity is a key driver of unnecessarily long lead times, and that simple systems and processes are paramount (Sheu and Wacker, 1997; de Treville et al., 2014).

Chaharsooghi and Heydari (2011) have investigated the effects of the mean lead time and the lead time variance on the performance of the supply chain. Furthermore Copra and Meindl (2006) claim that a supply chain consists of all stages in fulfilling a customer request. This is supported by Chaharsooghi and Heydari (2010) as they stress the importance of all parties involved in the supply chain on the overall lead time. The importance of different parties and the effects of information can also be seen through the so-called bullwhip effect. It can be described as an amplification of demand and order variability upstream (Zhang and Burke, 2011). Chaharsooghi and Heydari (2010) claim that one factor causing the bullwhip effect is lead times in the supply chain.

### 2.4 Traceability

In order to be able to analyze the effects of traceability on material replenishment lead times to a lean assembly line, several key aspects of traceability must be understood. Therefore, the following chapter presents definitions, advantages and technologies to achieve traceability within a supply chain.

#### 2.4.1 Definitions and Background

Traceability through the use of Automatic Identification and Data Capture (AIDC) systems has been a part of manufacturing for the last few decades (Han et al., 2011). It is used within many industries, but the automotive and food industries are said to be at the forefront regarding the implementation and evolution of AIDC systems within their respective supply chains (Dai et al., 2012; Nambiar, 2010). The primary gains for such systems might differ depending on industry and the company implementing it. For the food industry one main objective is to keep track of product flows in order to be able to track where bacteria comes from (Nambiar, 2010). Meanwhile, the main objective for the automotive industry is to reduce the uncertainty within production plans and schedules to manage a highly competitive landscape (Dai et al., 2012).

According to Cheng and Simmons (1994) traceability functions are vital, but add no direct value to the product. However, increased shop-floor visibility and traceability can "facilitate the implementation of advanced manufacturing strategies such as JIT lean manufacturing and mass customisation" (Dai et al., 2012). The real-time data that can
be collected in a system with high traceability greatly aids managers in making better-informed decisions (Fang et al., 2013; Dai et al., 2012). There is a variety of assessment criteria, like accuracy, completeness, speed and frequency which can be applied to the traceability system according to Cheng and Simmons (1994). Since industries change over time, the tracing system has to adapt in order to fulfill the changed requirements (Cheng and Simmons, 1994). Furthermore, as previously mentioned, different industries might have different objectives with their traceability implementation (Nambiar, 2010; Dai et al., 2012). This implies that systems might have to change in different ways in order to adjust to the changing environment.

Different technologies can be classified according to the objective and type of system to be implemented (Hodgson et al., 2010). An illustration of this can be seen in Figure 2.2. There is a variety of different systems that can be used to achieve traceability (Han et al., 2011; Hodgson et al., 2010). In this paper, focus is on so called "Data Carrier Technologies" presented by Hodgson et al. (2010). These technologies can encode and decode information through the use of three separate means: Optical storage, Magnetic storage and Electronic storage (Hodgson et al., 2010). The focus of this paper is specifically on the Optical storage through Barcodes, since Barcodes is the most established method for traceability (Schmidt et al., 2013; Hodgson et al., 2010).

![Figure 2.2: Illustration of how AIDC technologies can be distinguished by Hodgson et al. (2010)](image)

Table 2.1 shows some characteristics and uses of three types of AIDC systems presented by Han et al. (2011). As can be seen the technologies have different characteristics and are suited for different types of implementations and objectives.
<table>
<thead>
<tr>
<th>ID technologies</th>
<th>Characteristics</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barcode</td>
<td>Print, cheap, less data, read only (no write once printed)</td>
<td>Point of sales (POS), and material management</td>
</tr>
<tr>
<td>2D barcode</td>
<td>Print, cheap, read only, relatively more data than ID</td>
<td>Material management, and flight ticket</td>
</tr>
<tr>
<td>RFID</td>
<td>Non-contact, no line of sight, read-write capability, reusable, can read from some distance</td>
<td>Gate control, and POS, material management</td>
</tr>
</tbody>
</table>

Table 2.1: Comparison of ID technologies presented by Han et al. (2011)

### 2.4.2 Reasons for Traceability

There are many reasons to increase the visibility and traceability within a system. Examples are the facilitation of the implementation of more advanced manufacturing systems (Dai et al., 2012) and the ability to make better-informed shop-floor decisions (Fang et al., 2013). Cheng and Simmons (1994) has broken down the main reasons for the implementation of traceability into three areas, described below. Even though other authors do not call these reasons for traceability the same term as Cheng and Simmons (1994), the underlying message is echoed by Hodgson et al. (2010); Fang et al. (2013) amongst others. According to Cheng and Simmons (1994) the three areas are:

- "Status traceability is the ability of a system to provide accurate and timely knowledge of the current situation concerning the manufacturing system and traceability in manufacturing systems the environment in which it operates."
- Performance traceability is the system’s ability to provide data about progress against plans.
- Goal traceability is the system’s ability to illustrate what is needed to reach a set of goals.

Lee and Özer (2007) state that "with a real-time tracking technology, the manager can have complete visibility of inventory movement within the company at any point in time." They go on to argue that, in theory, Radio Frequency Identification (RFID) and other traceability enabling technologies "enables tracking and tracing of items in stock and in the pipeline, thus, creating complete inventory visibility, leading to an accurate account of inventory discrepancy." However, the authors stress that, for example, using RFID, requires "readers installed at appropriate locations" (Lee and Özer, 2007).

### 2.4.3 Technologies to Achieve Traceability

The following section outlines the technology of barcoding. Furthermore, a brief overview of ERP-systems is provided. Such systems play an important part in achieving traceability. The section describes both setbacks or weaknesses but also potential uses for the
Barcode

Barcoding is a method that "has become increasingly visible during the past decade, thanks to its widespread use in inventory/warehouse management, in supermarkets and other operations mainly in the retail sector" (Manthou and Vlachopoulou, 2001). It is regarded as the most established AIDC technology within manufacturing (Schmidt et al., 2013; Han et al., 2011; Klonis and Nabhani, 2010).

Barcodes reduce the risk of data errors resulting from manual input into the system (Han et al., 2011). Furthermore, barcodes are a proven and established technology for collecting data (Schmidt et al., 2013; Han et al., 2011). According to Klonis and Nabhani (2010) one reason for this is the ease of implementation and low installation cost of a barcode system.

However, there are some drawbacks connected to barcodes compared to other AIDC technologies such as RFID (Han et al., 2011; Schmidt et al., 2013; Gaukler and Hausman, 2008). One drawback is that work time is taken from the workers when using a barcode scanning system according to Gaukler and Hausman (2008) and hence they spend less time on value adding operations. Thus, it is not ideal for container management for example(Schmidt et al., 2013).

According to Akeroyd (2010), there are at least 30 different types of linear barcode symbologies, meaning languages that convert the relationship between black and white lines to data. This conversion is done by illuminating the black and white lines with either red or infrared light, depending on the system type (Osman and Furness, 2000).

Enterprise Resource Planning System

An Enterprise Resource Planning (ERP) system is a computer-based information system used for the integration of the entire enterprise (Olhager and Selldin, 2003). According to Nwankpa and Roumani (2014), companies are continuously investing in ERP-systems with the expectation to boost performance and generate value amidst increasing competition. However, the success of the implementation of an ERP-system greatly varies depending on various factors (Nwankpa and Roumani, 2014; Chou et al., 2014; Powel and Barry, 2005). Two of the more commonly mentioned factors are presented below.

- The extent to which the system is used by end-users within the firm. The more the usage, the higher the likelihood of gaining a competitive advantage
- The extent to which data in the system is integrated across the institution

According to Olhager and Selldin (2003), potential benefits of the implementation of a ERP-system include more easily accessible information and an increased interaction across the enterprise. Furthermore, Olhager and Selldin (2003) claim that "issues such as interaction with customers and suppliers, on-time delivery, operating costs, inventory levels and cash management" decrease. In addition, Chou et al. (2014) stress the possibility to analyze data in real-time and in an integrated way. However, Powel and Barry
Peysson (2010) describes the role of the ERP-system in traceability. Specifically, the process where raw material has to be approved within the ERP according to pre-determined rules is discussed. The possibility of using an ERP-system to increase the traceability is echoed by Lee and Park (2008), who describe how data regarding the Bill of Materials (BOM) from the ERP-system can be used for this.

2.5 Summary of Literature Review

The literature review described the literature used in this study. It started by explaining the lean context by outlining key concepts of the paradigm such as continuous improvement and waste reduction in the system (Green et al., 2010; Hines et al., 2004; Petersson et al., 2010). Furthermore, the seven forms of wastes according to LM principles were explained together with the importance of thinking in terms of internal customers as a basis for improvement work (Pfau et al., 1991).

Then, inventory replenishment decisions such as warehousing strategy, inventory strategy and reordering strategy were explained. Subsequently, reasons for inventory discrepancies such as "restocking or replenishment errors, database errors, poor or incomplete data synchronization, and counting errors" were explained (DeHoratius and Raman, 2008).

Since this study addressed the question of how an increased traceability affects material replenishment lead times, it was of importance to investigate how lead times can be shortened. Several reasons to why a company should strive to reduce its lead times were identified, such as lead time reduction as a source of competitive advantage and that it can lead to a reduction of demand exposure (de Treville et al., 2014). Furthermore, the complexity of the system was found to have contributed to long lead times in Sheu and Wacker (1997)’s study.

Finally, literature on the field of traceability was reviewed. Different industries have different reasons for implementing traceability (Dai et al., 2012; Nambiar, 2010). Cheng and Simmons (1994) claim that traceability is vital but adds no direct value to the product. However, the increased amount of data can facilitate the implementation of more advanced production systems according to Dai et al. (2012). Real-time data increasing the visibility and allowing for better-informed decisions to be taken and also minimizing the risk of inventory discrepancies are some reasons for increasing traceability according to Fang et al. (2013); Lee and Özer (2007). As a final step, the technologies of ERP systems and barcoding were described as two technologies that can be used to achieve traceability in a system.
Chapter 3

Method

The following chapter describes the method used for this study. It has been split into descriptions of the general approach, the research process, and validity and reliability. These sections in turn cover the data collection and data analysis method.

3.1 General Approach

Since limited research was observed to have been conducted in this specific area of research, the study was exploratory and consisted of a "how" question, for which a case study is the recommended approach (Yin, 2013). The study explored "how" an increased traceability affects the material replenishment lead times to lean assembly lines. According to Gattiker and Parente (2007) a case study is also the recommended methodology in operations management. This is echoed by Voss et al. (2002) who claim that case research has consistently been regarded as one of the most powerful methods in operations management. This study centers on the investigation of one specific phenomenon at a company, and thus a case-based research method was selected.

According to Collis and Hussey (2014) multiple data gathering methods can be used for a case study. This study has partly been based on qualitative data collection methods such as interviews and observations. These data collection methods are recommended for discovering new variables and relationships and to understand complex processes (Shah and Corley, 2010). However, the results were also triangulated with the use of quantitative data in order to increase the validity (Voss et al., 2002). The quantitative data was used to gain an understanding of the correlation between factors whilst the qualitative data was used to understand the complexity and causality. Similar approaches are recommended for case studies according to Gattiker and Parente (2007).

3.2 Research Process

This section outlines the research process used for this study. The relationship between lead times and traceability was deemed interesting both from an academic and practical perspective, and together with the case company and supervisor at the Royal Institute of Technology (KTH), an operational problem was defined. This problem was then broken down into more manageable pieces through root cause analyzes. Subsequently, a research question with three sub-questions was formulated.
The research was conducted in an iterative manner, meaning that as new areas of interest were identified, other parts were also affected. For example, empirical findings not covered by the literature review were added. Figure 3.1 is an illustration of the selected method.

The research was initiated through a background study consisting of a pre-study literature investigation. Four main areas were identified for the literature review, namely Lean Assembly (as a context), Inventory Replenishment, shortening of lead times and Traceability. These were selected due to their relationship with the main research question and in accordance with their deemed relevance to the research topic.

Then, interviews with various stakeholders at the case company were conducted in order to gain enhanced background information of the problems. These pre-study interviews were conducted in an unstructured manner in order to discuss the issues at hand and gain background information to plan the future research.

Subsequently, a context for the study was created through a main literature study. This created an understanding of the contextual importance of Lean Manufacturing as a paradigm and of issues concerning the inbound logistics to a lean assembly line.

The research centered on the four key areas previously described, but naturally sub-categories within these fields were explored as well. However, it was deemed important to set a limited scope for the literature review. Otherwise, there was a risk of getting overwhelmed by the amount of information collected (Collis and Hussey, 2014). The fields stated above combined to provide a theoretical framework to aid in answering all sub-questions.

The literature was collected throughout the research. Key information on the four focus topics was collected during the initial phase of the project. Specific and more in-depth
literature was added iteratively as the need arose.

The case study was used to empirically identify areas of improvement in the current material replenishment system. The data was partly collected through interviews and partly through empirical testing.

Data regarding the material replenishment system was then gathered from the internal ERP-system at the case company. The data was used to create an understanding of the correlation of factors in the system and to confirm opinions voiced in the interviews and observations made during the empirical testing. Data from the ERP-system was also gathered after the implementation of a scanning project to investigate the effects of traceability on a material replenishment system.

The final step was to analyze the gathered data. All sources of data were combined in order to create a good understanding of the entire material replenishment system as well as an understanding of the correlation and complexity of factors influencing it.

In the section below, the data collection for the overall process is described further.

### 3.2.1 Data Collection

The data collection process started by creating an understanding of the current situation and problem description. This was achieved during several visits on site, where logistics experts and production managers first gave guided tours and subsequently were interviewed in an unstructured manner. During the guided tours, the basics of the current logistics system were shown and described. Thereafter, the unstructured interviews served as a compliment in order to further understand the current state. The information collected during this phase was used to plan the future data gathering methods in order to further increase the validity of the research (Collis and Hussey, 2014).

Throughout the study, on average 2-3 days a week were spent in the factory in order to get an objective perspective of the current situation at the case object. This enabled assessment and reflection on the possibility of subjectivity in the interviewees’ answers. The theoretical framework created from the literature study was used to analyze the current situation of the logistics of the factory.

During the start up phase of the research project, unstructured interviews were conducted with employees at the case object. The interviewees were identified in collaboration with the case company in order to ensure that they possessed the necessary knowledge. Voss et al. (2002); Gattiker and Parente (2007) stress the importance of interviewing people with the necessary competence. These involved the Assembly Manager and three senior members of the logistics team. The goal of these unstructured interviews was to gain an understanding of the issues in order to define a research questions. All interviews were booked through our supervisor at the case company and conducted on site. Every person asked to participate in the study agreed and the interviews were conducted in Swedish, the native language of all interviewees. This was done to avoid misunderstandings due to linguistic aptitude.

Thereafter, semi-structured interviews were conducted with project managers of a scanning project that was to be implemented a few months after the start of this research. This was deemed important since the result of the scanning project would provide data
regarding the effect that a traceability increasing project would have on the current state. The objective of these interviews was to gain an overall understanding of the scanning project. A semi-structured interview was implemented in order to promote the interviewee to talk freely about the topic, which is the recommended way of extracting background information regarding a certain topic according to Collis and Hussey (2014). Additionally, a lean expert was interviewed in order to gain an in-depth understanding of the lean perspective on material replenishment. The interviewees were identified and contacted in the same manner as detailed above.

Subsequently, four key areas of interest were selected for the literature study. These were lean assembly as a context, inventory management, shortening of lead times and traceability. The first three weeks were dedicated to the literature study along with introductory interviews. Thereafter, the literature study was continuously updated throughout the entire research, but it was combined with other data gathering methods. The amount of time spent on the literature study per day decreased as the research progressed.

The next step was to conduct interviews with selected employees holding managerial positions at the case object. According to Shah and Corley (2010) interviews are often used to collect information of different perspectives on a topic. According to Voss et al. (2002); Gattiker and Parente (2007), it is important to seek out the best informed people when interviewing in order to gain accurate data. Hence, the interviewees were selected in collaboration with the case company to ensure that they possessed the necessary knowledge about the topic. The interviews were booked through the case object’s internal planning software and held on site. The duration of the interviews was approximately one hour long and the interviewees were always informed of the topic to be discussed prior to the interview. Appendix B illustrates what questions were asked during the interviews. These questions were designed to gain a detailed understanding of the research context. According to Collis and Hussey (2014), it is important to have a sufficient understanding of the context to ensure a high validity.

Furthermore, interviews with senior members of the logistics team at the case object were conducted in order to identify drivers of inventory replenishment lead times as well as to gain an understanding of the current situation at the case company. According to Voss et al. (2002), this is the main source of data gathering in case research. These were held in a semi-structured way, promoting the interviewee to express their own opinion (Collis and Hussey, 2014). Table 3.1 shows the interviews that were conducted during this study.
Table 3.1: Description of performed interviews

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Phase of research</th>
<th>Theme of interview</th>
<th>Length per interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM(2)</td>
<td>Pre-study</td>
<td>scanning project at case company</td>
<td>1h</td>
</tr>
<tr>
<td>LE(1)</td>
<td>Pre-study</td>
<td>The Lean Paradigm</td>
<td>1h</td>
</tr>
<tr>
<td>PM(1)</td>
<td>Pre-study</td>
<td>Measuring the Process</td>
<td>1h</td>
</tr>
<tr>
<td>SM(1), AM(1), LC(1), PM(3), LA(2)</td>
<td>Data gathering</td>
<td>Drivers of lead times and processes of the material replenishment system</td>
<td>1h</td>
</tr>
</tbody>
</table>

In Table 3.1 PM stands for Project Manager, LE for Lean Expert, SM for Site Manager, AM for Assembly Manager, LC for Logistics Controller and LA for Logistics Administrator. The numbers in parentheses state the number of interviews conducted with each respective class of interviewee.

The next step in the data gathering process was to conduct empirical tests investigating the current state of the material replenishment system through the use of process maps. According to Okrent and Vokurka (2004), using process maps allows for the identification of non-value adding operations and potential areas of improvement.

The inventory replenishment process at the case object’s factory was investigated using a method proposed by Green et al. (2010). Each step of the process was timed and a process map was created in collaboration with employees involved in the process. The objective was to identify the queue- and process times for each operation. This method can be used to map the current state and to measure the future state regarding lead times.

The process maps were made by following the product flow from the reception of incoming goods to the assembly lines. At each process along the way, employees were timed. In order to minimize the impact of different employee skill levels, multiple employees were observed at each process. The material replenishment system was divided into sub processes, which were identified in collaboration with key stakeholders at the case company. Okrent and Vokurka (2004) stress the importance of involving key participants of the process while mapping it, since it is said to be the most efficient way to gain an understanding of a process. Figure 3.2 illustrates which processes were investigated and how they were divided. During the course of the empirical testing, observations were noted and later used to analyze the causality of factors influencing the material replenishment system.
CHAPTER 3. METHOD

The final step of the data collection process for this study was to collect data from the case company’s internal ERP-system regarding the material replenishment system. The data required was specified to an ERP-specialist at the case company. The ERP-specialist thereafter provided the needed data when it was available. The data consisted of one year of logged timestamps in the ERP-system between the periods of March 2014 and March 2015. This resulted in approximately 76,000 data points for each control point in the system. The exact amount varied somewhat between control points. The data was used to further increase the validity of the results (Voss et al., 2002) and in order to be able to quantitatively understand the correlation between investigated factors. According to Boyer and Swink (2008) "multiple approaches are required in order to develop a holistic understanding of operations and supply chain management phenomena".

Half way through the study the case company implemented a scanning project, increasing the traceability of the material replenishment system. After one month, when the case company claimed that it had been fully implemented, ERP-data was gathered to investigate the effects of the project. The data was received in the same way as described above and represented 3 weeks worth of logged data during the first three weeks of March 2015. The data set represented approximately 5100 points of data for each control point within the material replenishment process. As in the previously gathered ERP data, the exact amount of data points varied between control points.

3.2.2 Data Analysis

According to Voss et al. (2002), the next step after collecting data is to document and code it. During the literature review, the collected articles were sorted into categories depending on themes. By keeping differently themed articles in different folders, a clear overview of the body of literature was kept. Thereafter, the literature was reviewed and presented in Chapter 2.

This study used qualitative methods to gather data as described above. The interview recordings were first transcribed and sent to the interviewees to be approved. In accordance with Voss et al. (2002), this was done as soon as possible after conducting the
interviews to ensure the data gathered was recalled in an accurate manner and to facilitate follow-ups and filling of gaps. As soon as the transcripts were approved they were coded into different themes. The themes for the coding were obtained through comparison of the interviewees’ responses in different sections of the interviews. A theme was created when interviewees answered a question similarly. Collis and Hussey (2014) state that coding is a way of analyzing interview data. This is echoed by Voss et al. (2002) who also claim that coding is central to effective case research. Coding allowed for the sorting of the collected data into main themes and subsequent separate data analysis. To be able to quote identified themes from the interviews, chosen quotes were translated to English. Original quotes and their translations can be found in Appendix A.

The quantitative data gathered from the case company’s ERP-system was processed in Excel. The data was in the form of time stamps for different processes. Different sets of data were combined by matching transfer request numbers to ensure that the different time stamps corresponded to the correct order. This step was undertaken in consultation with an ERP-specialist at the case company in order to ensure that the data was understood correctly and to limit confirmation bias. Thereafter the average lead times for various sub-processes of the material replenishment system were calculated. Subsequently, the data was inserted into the process map in order to gain an accurate and general view of the entire material replenishment system. This process was later repeated for the ERP data gathered after the scanning project.

The data gathered from the empirical tests was entered into an Excel file, where averages and lead times per article were calculated. These were then entered into a process map and subsequently combined with results from observations, interviews and ERP data. The empirically collected data was used to describe the causality, namely why a process took the measured amount of time, given the correlations observed in the larger, ERP collected data.

The results from the various data sources were eventually combined and analyzed together in order to answer this study’ sub research questions. This was done by dividing the results into themes answering questions according to the logic illustrated in Figure 3.3. This analysis eventually led to an answer to the main research question.
3.3 Validity and Reliability

According to Collis and Hussey (2014); Gibbert et al. (2008), reliability is the credibility of the findings. It signifies the accuracy of the measurements and to what extent differences would occur if the research were to be repeated. Validity on the other hand is an indicator of how well the test measures what the researchers actually want to measure (Collis and Hussey, 2014; Gibbert et al., 2008).

In this research a framework presented by Gibbert et al. (2008) has been used to evaluate the validity and reliability of the research. An applied framework can be seen in Figure 3.4 and mentions actions taken to increase validity and reliability. The areas investigated were internal validity, often called logical validity, construct validity, external validity, often called generalizability, and reliability.
### Internal Validity

- Pattern matching through comparison of empirical observations and theoretical contributions.
- Triangulation between various sources of data.

### Construct Validity

- Description of each step of the process allows the reader to follow the logical process of the study.
- Anonymity of case company reduces construct validity.

### External Validity

- All data from one case object can make results less generalizable.
- Results applicable to similar case objects.

### Reliability

- Transcripts of interviews sent to interviewees and approved before they were used in the report.
- Method of empirical test documented allowing for replication.
- Triangulation between various sources of data reduces risk of employee involvement in process.

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Figure 3.4: Applied framework for an investigation of the methodological rigor of case studies presented by Gibbert et al. (2008)

**Internal Validity**

Internal validity "refers to the causal relationships between variables and results" (Gibbert et al., 2008). Measures were undertaken to increase the internal validity of the study. First of all, the empirical observations were compared to theoretical contributions within the field, which Gibbert et al. (2008) calls pattern matching. In this report gathered ERP data was used to outline the correlation of factors, while the empirical data showed the causality of these factors. Furthermore, the use of triangulation within the data collection increases the internal validity of the research (Gibbert et al., 2008; Voss et al., 2002). The collected data was triangulated through the use of interviews, quantitative system-based data, and empirically collected data to understand the nuances of the research questions.

**Construct Validity**

Gibbert et al. (2008) describe construct validity as a measure of how well the research actually investigates what it is said to investigate. The authors mention two measures that increase the overall construct validity, which are to create a clear chain of evidence and to triangulate results. Both measures were take into account in this study. Each step of the research method is described, creating a chain of evidence, which allows
CHAPTER 3. METHOD

the reader to follow the structure and logic of the research. However, the name of the case company and the stakeholders interviewed were kept anonymous in accordance with a confidentiality contract with the case company. This reduces the construct validity somewhat, since it reduces the clarity of the chain of evidence.

External Validity

External validity, also called generalizability, is the extent to which the research can be applied to other settings (Gibbert et al., 2008; Collis and Hussey, 2014). All data gathered comes from the same case company. Hence, the data is case specific. However, the conclusions were divided into "theoretical" and "managerial" to put the results in a wider context. The theoretical contribution is applicable to other settings, but the managerial contribution is case specific. The reason behind this is that the case company had specific issues that were to be addressed during the project.

However, the results are applicable to similar case objects. The research cannot be said to be completely applicable to other settings, but it can be applied to similar settings and ultimately expanded upon.

Reliability

Reliability refers to the absence of random errors and how well the research can be reproduced (Gibbert et al., 2008; Collis and Hussey, 2014). This study relies heavily on qualitative sources of data such interviews and observations, but also on quantitative sources of data such as timestamps from the case company's ERP-system. According to Collis and Hussey (2014) qualitative sources of data are generally connected to low reliability.

However, measures have been taken to increase the validity of the research. One such measure was that transcripts of interviews were sent to the interviewees to gain their approval. This can be seen as a sort of case study protocol, which increases the transparency and therefore the reliability according to Gibbert et al. (2008).

Regarding the empirical testing performed during this research, the method has been documented to allow for replication of the study. Also, findings from specific data have been triangulated. Hence, the risk of low reliability due to allowing employees to be a part of the process mapping has been minimized. This increased the reliability of the study and allowed for the identification of potential random errors.
Chapter 4

Results and Analysis

This chapter consists of the results of the research and subsequent analyzes using interview quotes and pertinent academic literature. The chapter has been divided into sections, each containing results pertaining to a specific sub question. The first section outlines the current state of the material replenishment system, the second documents factors that drive the lead times, and the third contains results and analysis on the effects of an increased traceability.

4.1 Current State of the Material Replenishment System

The mapping of the current state of the case company’s material replenishment system has been split into two main sections; presentation of the inbound logistics process and problems with the current state as experienced by internal stakeholders.

4.1.1 Presentation of the Inbound Logistics Process

The following section presents findings from the documentation of the internal logistics process at the case company. The section describes the current state using academic literature as well as quotes from interviews with key stakeholders at the case company.

The case company utilizes a shared storage strategy, implying that articles do not have fixed storage locations. Instead, articles are allocated storage locations according to size and slot availability. This means that there can be multiple locations for the same article. The primary reasons the case company uses a shared storage strategy is to save warehouse floor space, and because they currently lack data regarding shifts in demand for each item, for example due to seasonality or fluctuations. The case company’s motives for using a shared storage strategy are backed up by Grosse and Glock (2014); Chackelson et al. (2013), who state that space utilization is high. However, both argue that space utilization comes at the expense of travel distance and product identification. According to the interviews and empirical observations, a shared storage strategy provides a simple interface for the data handling system for the workers, but complicates the underlying system requirements. Goetschalckx and Ratliff (1990) highlight the need for a complicated data handling system to make a shared storage system viable.
Articles are not picked from the warehouse in exact, ordered amounts. Instead, a container of suitable size is filled. A two-bin kanban system is utilized for re-ordering. When one bin is empty, a new bin is ordered. The picking strategy employed is a form of "picking by article" where multiple articles are picked and delivered to different orders. Picking by article is used to increase picking productivity by picking a number of articles heading in the same general direction in a single, unique tour according to de Koster et al. (2007). However, issues with de Koster et al. (2007)’s assertion were observed; the productivity can be drastically reduced depending on how the picking route is structured, or how items are retrieved from racks and paternoster works. In order to ensure optimal or highly productive routing, storage allocation and type of storage solution are definite parameters to be considered.

As new articles arrive to the factory the new stock balance is adjusted in the ERP-system. The actual stock balance of articles is not registered as used or spent until shipment of the finished product from the factory. Since articles are not picked to ordered amounts it becomes hard for the case company to know where specific quantities of a certain article are located in the warehouse. This approach, when assumptions of article quantities are made instead of actually counted, causes inventory discrepancies according to DeHoratius and Raman (2008). Even though DeHoratius and Raman (2008) investigate the phenomenon in a retail setting, the same principles can be said to be true for a producing company. As a direct result of stock discrepancies, the case company currently shuts down operations once a year and count their inventory. This process takes around three to four days. When this is done, amounts are corrected in the ERP-system to give a more correct representation of the current situation. There was an agreement from the interviewees that the inventory process had become a tool to balance stock issues rather than a way of reporting the capital worth of all items on stock, partly evidenced by the below quote:

"Inventory is a tool used to check a stock level, it is not meant to be used to balance stock" - Interviewee 7"

The working procedure as explained above, where stock balances are only registered as articles arrive to the factory and registered as used once the finished product leaves the factory, also causes a black box. This implies that the case company knows how much goes into the system and how much comes out, but do not know the balances in the middle. This implies that it is difficult to gather the wanted data for improvement work and also stresses potential quality implications. For instance, the lack of additional control points makes it hard to track faulty articles in the system and to eliminate the faulty batch of articles from production. Instead of working proactively, the case company is left putting out fires.

Main Flows in the Process

Figure 4.1 illustrates the two main flows identified during this study. The first flow is the physical product flow starting at the incoming goods unit and going through the material replenishment unit to the lean assembly lines. The second flow is the information flow, which goes in the opposite direction to the product flow.
All three units, incoming goods, material replenishment, and lean assembly lines, play important roles in the system that resupplies the lean assembly lines. The incoming goods unit ensures that material is present in the warehouse from where the material replenishment unit picks material according to orders received from the assembly lines.

The units' functions are best illustrated by dividing them in two: resupplying the assembly lines and resupplying the warehouse. The reason for this division is that an order from the assembly lines does not directly trigger an order for the incoming goods. If there is material present at the warehouse, the material resupplying unit simply bypasses the incoming goods unit until a refill of the warehouse is needed.

**Resupplying the Assembly Lines**

This sub-process is triggered by the assembly lines ordering new material. The assembly lines aim to always have two bins of material at their on-site storage. When one is empty, they scan a barcode attached to the bin to trigger a re-order. This order is then sent directly into the ERP-system, where the material replenishment unit can access it. Figure 4.2 is an illustration of the process that starts after the order has been placed by the assembly lines. The first step for the material replenishment unit is to print orders and corresponding barcodes. This is done in the form of long lists printed two to three times a day. The barcodes correspond to a certain box containing an unknown quantity of an article.

The next step is to sort the printed lists. Each printed page contains 13 articles to be picked. The correct barcodes have to be found, identified and attached to the correct lists. The sorted lists are then placed in a holder where the order pickers can collect lists and start a picking round. This work is done by the material replenishment pickers, and can be grouped as a "non-value" adding activity, or a waste, according to definitions of LM by Green et al. (2010); Petersson et al. (2010); Liker (2004). The manual handling of the lists was also identified as a potential error source in the interviews, and the process was often described as "outdated" as seen in the below quote.

"I think it is an outdated method to handle transfer-orders (lists)... to do so on paper that then have to be sorted." - Interviewee 6
The term "outdated" occurred often during the interviews. When questions were asked about the level of awareness regarding manual errors and long lead times as a result of printing lists, the overwhelming majority answered that they were in fact aware of the issues. However, whilst the awareness was present, there were few ideas as to how to find the optimal solution or how to collect more data to make better informed decisions. According to Fang et al. (2013); Dai et al. (2012), a system with high traceability aids in decision making. However, from the case study the opposite relationship has been observed; a system with low traceability hinders decision making due to the limited amount of data available. Whether this is solely due to low traceability is debatable, but a material replenishment system that collects data at regular intervals and allows for simple, robust processes is more foreseeable according to Sheu and Wacker (1997).

The subsequent step in the process is to pick the articles or items specified on the sorted lists. There are usually two different types of picks; picks from rack storage and from picks paternoster storage. The normal picking route is usually a mixture of both, but sometimes it contains only rack picks. The exception to this is the person who has responsibility over the emergency phone, which is a secondary flow in the material replenishment process explained later in this section. This person only picks from paternoster storage. He or she has to leave his or her main route to complete emergency picks, which is not suitable if you have to use a forklift for rack picks. The main flow and the secondary flow are described below in Figure 4.2.
When working the normal picking rounds, workers take a printed picking list and walk from isle to isle in the warehouse picking articles according to order. The order pickers decide the picking route by themselves; there is no automated system that calculates the shortest route for them. Since a shared or random storage strategy is used, the length and complexity of these routes varies greatly and essentially takes a long time proportionate to the relatively short factory routes. This result was expected as it had already been observed and documented in literature by de Koster et al. (2007) amongst others.

The picker then fills up a predetermined sized bin, places the full bin on his or her cart and continues until he or she has picked all orders on the list. If a material is not found in the designated location, the picker goes to a computer, located at various locations throughout the warehouse, and looks up another storage location for the specific item. If the material is found somewhere else in the warehouse it is picked from there. Otherwise,
the material is re-ordered for the assembly lines by the material replenishment unit.

If there is no material present in the warehouse new material is ordered from suppliers and brought into the system through the incoming goods unit, which is described more in depth later. The same process applies if there is insufficient material in a bin. If this is the case, the picker collects the material barcode located inside the bin and places it on the picking list. These barcodes are later used to report the bin as empty so that the incoming goods unit can refill the storage location. As a result of the case company using shared storage, up to ten different locations for the same material were observed during the course of the research. Since the case company utilizes a First In First Out (FIFO) system, the ERP-system has to keep track and give the picker the location of the oldest batch in storage. This puts higher demands on the ERP-system than if a fixed storage strategy was used, which is supported by Goetschalckx and Ratliff (1990).

When all articles have been picked, the picker takes the cart and delivers the material to the correct storage location at the assembly lines. The pickers select their route by themselves and have no system support to tell them that all items have been exhaustively delivered to a certain location before moving on. This implies that the picker might have to return to a location if the article was misplaced on their cart or if they simply missed it. This was observed to happen alarmingly often. Literature has attempted to solve these issues through systems integrating visual prompts, often times in combination with some sort of routing strategy (Reif and Günthner, 2009). However, it is apparent from Reif and Günthner (2009) that such aids require significant system support to be useful.

When all articles have been delivered to the assembly lines, the picker returns to a computer and confirms all picks. The picker scans a barcode confirming that the order has been completed. During this operation they also scan the collected barcodes from emptied bins throughout the warehouse and report them as empty. When the bins have been reported empty, the main picking process is completed. The picker can now either take a new picking list to restart the picking process or print new lists if there are no more printed lists present. In essence, the case company uses scanning as a form of traceability, but only from certain locations and in certain situations. These situations are limited to the start and end of the material replenishment process, meaning that the majority of the process has little to no traceability and real-time error checking. The system appears to lack "status traceability", which in turn makes it difficult to achieve "performance traceability" as defined by Cheng and Simmons (1994).

The secondary flow consists of an emergency telephone, which is used when the assembly lines are in urgent need of an article that has been ordered but not yet been delivered. Since the assembly lines have two bins of each material the emergency service should, in theory, be used only in rare cases. However, the assembly lines sometimes forget to re-order material in time, putting the material replenishment unit under pressure and forcing the assembly lines to use this secondary flow. There is always one picker in charge of the emergency phone. This person only picks out of the paternoster storage, since he or she has to be able to divert from the main picking route quickly to see to the needs of the emergency calls. When a call comes in the picker picks the article and delivers it at once as fast as possible.
Resupplying the Warehouse

As stated above, the incoming goods unit resupplies the warehouse and allocates storage locations to incoming material. In this section, this process is described further. However, the case company’s interaction with suppliers is outside of the scope of this paper. The process is therefore only described from the moment that the material enters the factory.

Figure 4.3 illustrates the different steps of this process. When the material enters the building, the incoming goods unit first has to receive the goods. This is done by entering information on the incoming material into the ERP-system. The information is entered at either one of two computers located at the receiving dock.

When these steps have been completed, the material is placed on a conveyor belt which takes it to another workstation. Here, each material is allocated a storage location. The workers assigned to this station first have to decide which size of bin is needed for the material and then he or she receives a list of free, unoccupied locations in the warehouse. The employee selects a bin, prints a transfer order, places the material barcode on the order and then places the material on a cart.

When the cart is full, another person takes it and transports the material to the designated storage location. There is no system support to calculate the shortest route, instead each
employee walks from isle to isle placing the material in the correct storage location. He or she knows where to place the material by reading the printed transfer orders.

When the cart is emptied, the employee returns to the receiving dock and scans each transfer order. This confirms that they are completed and as a result the material is checked-in to the storage location in the ERP-system, meaning that the material replenishment unit can see them and collect them during their routes.

The process of resupplying the warehouse involves numerous instances of manual handling and processing. For instance, the first step of receiving the incoming goods is dependent on entering the correct article number and correct quantity. After the storage location has been automatically, randomly assigned, items are manually put into their designated storage locations. This is another potential error source, since it is easy to confuse different storage locations with each other and put the items into the wrong position. According to DeHoratius and Raman (2008), manual handling is a major source for inventory discrepancies. As the items are confirmed in the ERP-system at a separate location and at a later stage, errors are not discovered in real-time but rather at a later point in time, often as a result of inventory checks or difficulty in completing an order. Many interviewees saw this as a quality problem. The below quote illustrates that the support provided to the material pickers was deemed insufficient.

"The technical solution in the ERP-system does not allow for us to pick efficiently... The internal customer suffers." - Interviewee 1

According to Pfau et al. (1991), it is important to understand the internal customer’s needs and expectations and to thereafter understand the extent to which these needs are being met. There is a lack of both in the process of resupplying the warehouse, and processes are designed with their own work tasks in mind more than the internal customers’ requirements. This could be seen as a problem throughout the organization as Pfau et al. (1991) state that excellent service to internal customers oftentimes corresponds to having highly satisfied external customers.

### 4.1.2 Problems with the Current State as Experienced by Stakeholders

In this section, results from the eight interviews with stakeholders at the case company are presented. These interviews constituted the qualitative part of this research paper’s method. The section serves to outline the key problem areas with the material replenishment system as experienced internally. Investigating the difference between the mapped current state and the current state as experienced by internal stakeholders at the case company offers insight into differences of how the system is perceived. The findings are used to better understand the current state as experienced by stakeholders at the case company.

The results have been attained through inductive content analysis of the interview data from the transcribed interviews. Four main themes within the current replenishment system at the case company were identified across the interviews. They are presented in the list below. There are overlaps between themes but they have been kept separate in the results section to accurately represent the interviewees’ answers and to remove as much
confirmation bias as possible. For instance, the theme of inventory discrepancies was broken down into inventory discrepancies due to supplier errors, in-house errors, retroactive approach and due to seeing the issue as inevitable and acceptable. The following sections document the main themes and their intricacies.

- Manual processing errors
- Issues with ERP-system and ERP-processes
- Inventory discrepancies
- Long internal lead times from placement of refill order to order completion

These themes are handled separately below. They are supported by relevant quotes and comments taken and translated directly from the interview transcripts. The original quote can be found in Appendix A.

Manual Processing Errors

All eight interviewees highlighted manual, human errors as a large problem area in the current material replenishment setup. This was often attributed to an over-reliance on visual controls or a lack of controls in the ERP-system. Examples of the errors included:

- Loss of articles during handling
- Compromised quality during repackaging and handling
- Difficulty in counting the inventory level
- Placing an article in the wrong storage bin
- Picking an article from the wrong storage bin

Interviewee 2 highlighted many of these errors and attributed them to their opinion that the logistics personnel currently have few controls to help them avoid these errors, evidenced below.

"We only have visual controls today. That’s probably a big reason that we put items in the wrong bin, that we have inventory balance issues, that we don’t know where our inventory is" - Interviewee 2

Naturally, the various manual errors were experienced differently depending on the stakeholder’s position and job description, though there was an agreement about the nature of the issues. For instance, Interviewee 6 highlighted similar errors as Interviewee 2 but from a more practical perspective.

"We register the wrong quantity as goods received, we shift materials and place the wrong items in our storage racks and paternoster storage. We lose items, items sometimes never make it to their designated storage location, different items are mixed in the same bin but are registered as the same item." - Interviewee 6

Many of the errors identified by employees at the case company were similarly observed during the empirical observations in this study. However, there was little to no data on how often the errors were observed. Whilst the errors are known, they have not been
made tangible as their prevalence is unknown. Thus, the importance of each issue was oftentimes dependent on the interviewee’s position and personal motives. For instance, one of the most prominent and easily observable difference was that some interviewees adopted a strategic approach whereas some adopted a more practical, in line with their roles at the company. An example was that the errors were reported by one interviewee to be a hassle for factory workers and a source of frustration, whereas another interviewee answered the same question by identifying the amount of safety stock and capital required to gloss over the errors to keep the factory running.

**Issues with ERP-System and ERP-Processes**

The setup of the ERP-system was a recurring problem discussed in all interviews. The key issues are mentioned below:

- Joint, virtual storage location in ERP-system for separate physical locations
- System only registers stock balance twice from goods received to finished product

The first issue discussed was that different storage locations are not differentiated in the system, rather they are all registered in a fictive "virtual" location, meaning that there is no way to determine the quantity of a certain item at a certain storage location. Another widely discussed issue was that the system only registers stock balance twice during the whole internal logistics process; when the items are goods received, and when fully assembled, tested, and packed tools leave the factory.

Essentially, the current state of the system does not allow for real-time data analysis as stressed by Chou et al. (2014). There simply are not enough points along the process where data is collected to relay accurate real-time data. According to Powel and Barry (2005), an ERP-system works best when it has been specifically adjusted to the enterprise in order to reach the full potential benefits as most ERP-systems are generic to ensure wide ranging functionality. However, the current ERP-system in place satisfies the needs of the material replenishment process as it is setup today. This sentiment was echoed internally within the case company as orders are often completed and critical errors usually mitigated. Having said that, the current setup is complex and promotes retroactive work to fix problems. To achieve a more efficient setup, interviewees sought a more logical, integrated, and real-time based system. Two examples of this can be seen below.

"The ERP-system ensures that the possibility of having an efficient material replenishment system is limited" - Interviewee 1

"If we are talking about the electronic system, we today lack full system support regarding material replenishment. From the moment an order is received from assembly till we deliver the order, there is no logic in the system at all." - Interviewee 3

The issue with the virtual storage location was discussed by all, but highlighted by interviewee 6 in the subsequent quote. Borrowing from virtual was considered an issue because there was no traceability or information as to where the borrowed item is in the factory or which processes it has gone through.

"We borrow everything from "virtual." And when we then empty a storage
location, then we refill in virtual, so there is always a balance there, but never at a specific storage location.” - Interviewee 6

**Inventory Discrepancies**

Inventory discrepancy was most frequently mentioned issue during the interviews. The issue was divided into four main problem areas as per below.

- Inventory discrepancies due to supplier errors
- Inventory discrepancies due to in-house errors
- Retroactive approach to dealing with inventory discrepancies
- Inventory discrepancies as the "norm"

Interviewee 7 highlighted that supplier errors are not always detected when deliveries are made to the factory, as specific quantities and balances are only randomly checked, a happening similarly observed by DeHoratius and Raman (2008). The incoming goods can be flagged for quality inspection if the supplier is known to supply goods with quality issues, or a random sample of incoming goods can be tested. Thus, all incoming goods are not tested for quantity and quality. Interviewee 7 describes various error sources in the following quote.

"It can be deviations from the supplier, differing quantities, quality deviations. These are pure supplier errors. It can also be a component error or a documentation error." - Interviewee 7

In-house errors were seen as another potential source of inventory discrepancy. There was an agreement that errors stemmed either from insufficient or defective processes or that the logistics workers simply did not follow the stated procedure. These problems were all observed first hand during the empirical testing, for example in the form of articles being misplaced or dropped on the floor. DeHoratius and Raman (2008); Lee and Özer (2007) both state that excessive movement of stock due to inefficient procedures or processes are big causes of inventory discrepancy. This rings true for the inventory replenishment process at the case company, where each item is handled extensively.

The empirical observations also lead to an agreement with the interviewees in that there are numerous internal problems that cause discrepancy such as supplier errors and in-house errors. Having said that, the case company differs from other examples in other studies in that the actual system setup, with control points and traceability functions in the ERP-system, is a source of inventory discrepancies. The lack of control within the setup contributes to the uncertainty, and gives employees freedom to do as they please. For instance, a lost or damaged item is not considered important to the material replenishment workers because it is never controlled and the actual damage done is seldom felt, echoed by Interviewees 7 and 8 below.

"It can also be purely due to errors from us internally. Inadequate processes maybe, or the fact that we don’t follow the stated processes and things like that." - Interviewee 7
"Things happen, we lose an item here, count items wrong, someone was distracted or entered the wrong input into the system." - Interviewee 8

Thirdly, the case company’s retroactive approach to dealing with inventory discrepancies was identified as an area of concern and a reason as to why little improvement was made regarding stock balance issues. Again, this was observed throughout the empirical data collection; issues were handled as separate cases that were investigated and fixed for the moment. However, even though similar issues appeared often, there was no proactive approach to problem avoidance. Industry reports based primarily on other case studies in academic literature claim that a high visibility has the potential of reducing inventory discrepancies (Lee and Özer, 2007). Without a high visibility, the case company is left putting out fires, as stated by Interviewees 7 and 2 below.

"We solve every stock balance fault for the moment, or we actually don’t solve it, we address the fault so we can move on. We don’t solve the problem and we don’t check for the root cause. We have the same type of stock balance fault the day after." - Interviewee 7

"There is very little proactive work being done within the internal logistics setup." - Interviewee 2

Lastly, there was a consensus that the issue with stock discrepancy has become such a widespread occurrence that it is accepted and something that is worked around. Most interviewees were aware of the factory’s inventory discrepancies and claimed that they dealt with the issue on a daily basis. Below are three typical answers to questions regarding the awareness of the stock balance issues.

"I think many view stock balance faults as a problem." - Interviewee 8

"Stock balance faults is a problem that the whole factory is aware of, I think." - Interviewee 7

"Stock balance faults is viewed as a problem, but I don’t think that we take it seriously enough, bearing in mind that we have continuous faults." - Interviewee 1

**Long Internal Logistics Lead Times**

There was a general agreement amongst the interviewees that long internal lead times constituted a significant problem for the replenishment process. There was also a high level of conformity regarding the causes for the long lead times. The most common causes are listed below.

- Inefficient (re-packaging, internal movement and transport)
- Warehousing and stock-keeping complexity
- Widespread usage of storage racks over paternoster works
- Emergency telephone process

Below follow quotes that illustrate typical answers that are summarized by the above listed causes.
"The feeling I have is that the internal logistics is very inefficient. We repack and pick a lot of items." - Interviewee 5

"Then we are talking about the complexity. Since we haven’t changed anything for a long time, that means that if it was an easy fix we would have done it in my opinion." - Interviewee 5

"It takes a very long time to get an efficient logistics setup using racks. You have to drive the truck, lift the material up and down, and you have racks that take up a lot of space." - Interviewee 1

"You can see that when the amount of work increases, so too does the amount of calls to the emergency telephone. Some find it stressful to be in charge of the phone when the workload is high." - Interviewee 3

The listed causes are all processes or issues that are tangible and can be observed visually. However, a lead time incorporates all parts of a process, including LM wastes such as waiting (Petersson et al., 2010), and these are not always as easy to detect when you are involved in the daily running of the processes. This is a key difference between how the material replenishment lead times were experienced internally and how they were observed. Many of the issues stated above are warehouse strategy specific rather than inventory strategy specific. However, Interviewee 1 stood out with more of a focus on inventory strategy, where Interviewee 1 was convinced that an inefficient inventory strategy was driving process issues in the warehouse.

"Somehow we have to work with managing and reducing our storage parameters gradually together with working with the internal logistics" - Interviewee 1

This relationship was observed, as well as the reverse, where the processes were driving the need for safety stock and making it difficult to set short-term forecasts.

### 4.1.3 Summary of the Current State

The case company uses a shared storage strategy, which puts high demands on the data handling system according to Goetschalckx and Ratliff (1990). However, articles are not picked in exact, ordered amounts. Instead, a bin of a predetermined size is filled when an order is being processed. The case company uses a two-bin kanban system, meaning that assembly lines re-order articles when one bin has been emptied. The pickers then pick the articles according to lists that are printed two to three times a day, a time consuming and inconsistent process. The actual picking routes were not optimized and pickers themselves decided which route to take. Due to the case company’s strategy of not picking to exact amounts, there is no way of knowing the exact amounts of a certain article in the warehouse, which was found to be problematic in practice as well as stressed as an issue in academic literature.

The current process of resupplying the warehouse in case of stock-outs has numerous instances of manual handling. For example, the receiving goods process is dependent on the employee first entering the correct article number and quantity. Thereafter, when the articles are manually put into the assigned storage, another potential area of errors...
arises. As the confirmation to the ERP-system is not done simultaneous to the process, errors are not detected real-time but rather at a significantly later point in time.

Four main problem areas were identified from the interviews with internal stakeholders; manual processing errors, issues with ERP-system and ERP-process, inventory discrepancies and long internal lead times. The first problem area, manual processing errors, included the loss of material and misplacement of articles. The second problem area included the main issues with the ERP-system and ERP-processes and the lack of a differentiation between storage locations in the system, where material instead was registered in the same virtual location. Additionally, the stock balance was only registered and confirmed twice during the entire process, meaning that there was no relevant up to date data available and that a black box effect was created. The third problem area of inventory discrepancies was seen as perhaps the biggest issue by the internal stakeholders; numerous error sources were identified, yet the lack of traceability and a retroactive approach to dealing with the errors meant that ultimately little was done to fix the problems. Finally, long internal lead times was mentioned as a problem. Only visible or tangible problems with the processes were mentioned, whereas the empirical observations identified wastes throughout the replenishment system.

4.2 Factors Driving Inventory Replenishment Lead Times

This section identifies and explains factors driving the material replenishment lead times at the case company. This was done by first identifying key processes from the ERP data. Then, the results were combined with results and observations from the empirical testing. This was done to explain both the correlation and causality of the results from the ERP and empirical data.

There is a consensus in academic literature that the complexity of a system drives lead times (Sheu and Wacker, 1997; de Treville et al., 2014). This would imply that a simple and well designed system would automatically result in short lead times. However, Fisher (1997); de Treville et al. (2014) state that numerous companies struggle to reduce their lead times. The absence in literature of specific action plans on how to reduce lead times suggests that there is no general, standard solution to the internal lead time problem. Each system has to be individually fit to the specific situation.

4.2.1 Results from ERP Generated Data

In this section, the results from the ERP generated data are presented and analyzed. The data gathered represents one year of logged timestamps from the material replenishment process. The data has been represented as the relative quantity of measurements within a certain time span. For illustration purposes, a logarithmic y-axis was selected due to the low frequency of some data points. The results have been divided into three subcategories together illustrating the entire material replenishment system. The different categories, which are described further below, are:

- The overall lead time
The Overall Lead Time

The overall lead time of the system was calculated from the time that the assembly line orders an article to the moment that the order is confirmed as delivered by the material replenishment unit. A total of 75,778 data points were gathered from one year. Thereafter, the data points were grouped in one hour intervals and the results plotted in a graph. The results are illustrated in Figure 4.4.

As seen in Figure 4.4, there is a concentration of data points in the beginning of the process. 76% of deliveries are completed within the first 48 hours after the assembly lines placed the order. However, there are observations where it takes substantially longer, resulting in an average total lead time of 99.78 hours. This is stressed as an issue by Interviewee 7 who claims:

"If we regard that we try to reduce the production lead time to 1-2 days from loose components arriving at the assembly lines to a complete and tested product. Then 24 hours to receive the needed components is horrible" - Interviewee 7

The case company has accepted a 24 hour lead time for internal resupplying of products. However, they work towards takted flow in the assembly line and constantly improving the assembly lead times. It is important to stress this difference in mindset, where one part of the process is working with lean principles while the support functions are not. This is alarming, since the material replenishment process might hinder the lean work in the assembly lines from reaching its whole potential if not adjusted. Domingo et al. (2007) stress the importance of the material replenishment system to a lean assembly setup.
Furthermore, Hauser et al. (1996) and Pfau et al. (1991) claim that the possibility of satisfying the internal customers’ needs is directly correlated to meeting the external customers’ needs. Hence, not having a satisfactory material replenishment might hinder the effects of the conducted lean assembly work.

In addition, some values greatly varied from the norm. If Figure 4.4 is investigated closer, it can be observed that the higher lead times are not present in the same frequency as the significantly lower lead times. Rather, a long tail of outliers is created when plotting the results. These outliers constitute the data points outside the normal values for the process. One possible reason for these outliers are stock-outs since the order is not printed unless material is present in the warehouse, meaning that it stays in the ERP-system. Another possible reason is system errors, meaning that the system claims that there is material in the warehouse, even though there is no assigned storage location. As a result no new material is re-ordered from suppliers. Since the system cannot find any storage locations, the order is not be printed. This results in orders being in the ERP-system for a long time before being handled.

After investigating the internal ERP-system at the case company, it was determined that the average delivery time from suppliers after a stock-out was 30 days. This implies that orders are in the system for an average of 30 days before being printed following a stock-out. In order to incorporate the time spent picking and to give a better representation of the normal situation of the material replenishment process, the average picking time was added to these 30 days, resulting in a time of 738 hours. When removing the data points outside the first 738 hours the results become substantially different. The results from when the outliers were eliminated is shown in Figure 4.5.

![Figure 4.5: Lead time from order to delivery without outliers for the current state](image)

In Figure 4.5, 96.98% of the total data points are represented. For these data points the average total lead time is reduced to only 49.25 hours. The extent of the variation in times measured, shows that improvements can be done. This is echoed in the interviews as interviewee 8 claims:
"We have not optimized this system. We have had it in one way when we were a smaller company and then we have only let it grow on." - Interviewee

The long tail caused by outliers and stock-outs, can hinder the production of the case company since assembly lines have to wait a long time for the needed material. This is echoed by Domingo et al. (2007), who claim that a long lead time hinders the synchronous flow of material, which is an important aspect when supplying lean assembly lines. One reason why this process has not been improved upon might be that the case company focused on the value-adding operations of manufacturing and assembly. Myers and Stephens (2000) describe the material replenishment process as non value-adding, but necessary to the overall completion of products. As long as the material replenishment unit completes its tasks and supplies the assembly lines with the necessary material, it might not be identified as a process important to the competitiveness of the company. This is supported by the interviews as the case company seems to hide issues with the material replenishment system due to high inventory levels. Interviewee 4 and 1 discuss this in the below quotes.

"Traditionally we have been working with high safety stock levels to manage the fluctuations instead of working with the system to achieve a even flow throughout." - Interviewee 4

"This implies that we hide many of our problems I think, because when we build up our stock levels many of the problems are hidden." - Interviewee 1

In the following sections the overall lead time is broken down into subcategories to better understand the drivers behind this result.

The Material Replenishment Process

The material replenishment process can be broken down to illustrate the time spent before the process is initiated by printing order lists and also the time spent picking the orders. In this section the results from these distinctions are shown.

The first step in the material replenishment process is to print the order lists. As can be seen in Figure 4.6, 86% of the orders are printed during the same day as they are received. However, some are left substantially longer in the ERP-system before printed, resulting in an average time before printed of 82.81 hours. Furthermore, a similarity to Figure 4.4 can be seen. This further supports the theory that the outliers partly are due to system errors, where orders are not being printed since there is no assigned storage location, but also that items are not re-ordered from the suppliers since the system claims that there should be material in the warehouse.
Figure 4.6: Time from material order to printing of transfer order for the current state

Figure 4.6 shows that even though there is a great difference between the shortest and longest observed time between the assembly lines ordering an article until the order has been printed by the material replenishment unit, the majority of data points are within the first 24 hours of the process. As stated before, the average delivery time from suppliers after a stock-out is 30 days according to the case company’s ERP-system. Since orders are not printed unless material is present in the warehouse and there is an average delivery time of 30 days from suppliers, the normal state of the process can be found during the first 30 days (720 hours). Anything above this can be seen as an outlier and subsequently removed. Figure 4.7 represents the result without outliers.

Figure 4.7: Time from order to order list printed without outliers for the current state
In Figure 4.7, 97% of the data points are represented. This illustration is of interest since the picking lists are printed two to three times per day, also observed during the empirical testing. This is echoed by Interviewee 7 as they stated:

"They (the lists) are collected maybe twice a day instead of doing it continuously. That means that we say that we have a 24 hour lead time there and we maybe manage that in most cases." - Interviewee 7

Hence, the longer lead times can either be due to orders being placed on Friday and therefore not processed before Monday or due to stock-outs, meaning the order is not printed until the material is received. For the data represented in Figure 4.7, an average time of 32.51 hours from order by the assembly line to printing of the order list was observed.

Even though this is substantially lower than when the entire set of data is used, it is still a big part of the total lead time of the material replenishment process. When comparing the entire sets of data, 82.99% of the total lead time is spent before even printing the order lists. After removing the outliers the same is true for 66.01% of the total lead time. This waiting process is not adding any value to the product and can therefore be seen as a waste according to the lean principles and should be eliminated (Green et al., 2010; Petersson et al., 2010; Liker, 2004). It might also indicate that stock-outs are relatively frequent and have a big impact on the total lead time. The case company stresses that they have high inventory holding costs, which makes the occurrence of stock-outs alarming. Normally, stock-outs should not occur frequently. Nenes et al. (2010) stress the importance of having a balance between service level, meaning frequency of stock-outs, and high inventory holding costs.

The next step in the material replenishment process is to pick articles according to the printed orders. As can be seen in Figure 4.8, 53.9% of all printed orders are picked within the first 12 hours and 87.9% are picked within the first 24 hours after printing. There is a long tail of longer lead times, even if the majority is situated within the first 24 hours. This results in an average picking time of 16.97 hours when looking at the entire set of data.
In order to analyze the most common state of the sub-process and to be able to draw conclusions about the process, the first 34 hours of the process is printed in Figure 4.9. Here, two distinct peaks can be observed. One reason for this is that the material replenishment unit only works day time and therefore orders that are not picked during the first day are handled during the beginning of the next.

When outliers are removed, a total of 91% of the data points are included in the graph and the average time spent picking is reduced to 11.96 hours. One aspect with these results regarding the material replenishment process is that the case company sees the
picking procedure as a major problem in the material replenishment process, as seen in the following quotes.

"The time to make a pick takes too long. Both to put material into storage and to pick it out of storage." - Interviewee 1

"We are definitely re-picking material very often, transporting it between racks, back and forth actually until it eventually lands in the assembly line." - Interviewee 6

The observations on the importance of the picking process to the overall cost of an inventory management system are echoed by Strack and Pochet (2010). However, the results from the gathered ERP data shows that the picking time only makes up for 24.30% of the total lead time of the material replenishment process at the case company when looking at the data where outliers were removed. Hence, the time before printing is of great importance to the total delivery time.

When analyzing the interval where the majority of the data points can be found, the process of printing the order lists stands for on average 32.51 hours. The average time for the normal case of picking was 11.96 hours. However, since stock-outs only influence the average time before the lists are printed and not the picking time it can be argued that the process itself does not take on average 32.51 hours. Instead it is an indication of the effect of stock-outs and system errors on lead time. Therefore, it can be said that both sub-processes are of great importance for the total lead time.

The Incoming Goods Process

The incoming goods process can also be broken down into sub-processes. These processes are the time between receiving a new article and assigning a storage location, as well as the time between assigning a storage location for an article to confirming it as stored in that location.

The first step of the incoming goods process is to receive the newly arrived material. Thereafter, a storage location is allocated. From the gathered ERP data, the lead time between receiving new material and assigning a location can be investigated. The results are illustrated in Figure 4.10 and show the amount of data points between one hour long time spans.
In Figure 4.10, 42.2% of the incoming material is allocated a spot within the first hour after being entered into the ERP-system. After 24 hours 85.19% has a space allocated. The high amount of data points situated within the first 24 hours of the process is no surprise, since the case company has a policy which states that all goods should be received before the end of the shift. This results in an average lead time of the process of 18.17 hours when looking at the entire set of data. However, there is a long tail of infrequent outliers. When these are removed in order to investigate the normal case of the process by removing data points after the first 30 hours, the data set is modelled by Figure 4.11.
The result of removing these outliers is that the average lead time of the process is reduced to 4.49 hours. This reduction, from 18.17 to 4.49 hours when removing 14.81% of the data points, shows that the removed points have substantially higher values than the norm. This variation might partially be attributed to quality inspections being performed. However, some of it might also be due to a process low in precision. This is supported by Interviewee 1 who claims that:

"I do not think that they work especially efficiently in the receiving goods and material replenishment units. Partly because they do not have the tools, by that I mean technical aids to handle the ERP-system, and partly because the flow has never, or I should not say never, but the flow has not been mapped and investigated for potential improvements." - Interviewee 1

This statement suggests that the incoming goods process has not been improved for some time. This is discerning, since the incoming goods process is part of the overall system creating customer value. Hence, if this process is not optimized, it might hinder the overall performance. As stated before, Hauser et al. (1996) and Pfau et al. (1991) stress the importance for the overall performance to satisfy internal needs. There might be different reasons to why the process is not performing at a satisfactory level. As can be seen Figure 4.11, the average lead time for the normal case from goods received to allocation of a storage location is 4.49 hours. This time is in the form of "waiting", where the articles are placed on a conveyor belt prior to being processed. This is a waste time that should be removed according to LM principles on waste removal (Green et al., 2010; Petersson et al., 2010; Liker, 2004). Rather than regarding the removal of waste as a practical problem, the issue should be seen as strategic in this case. This is supported by the current strategy for the incoming goods, where goods have to be received the same day as they are delivered to the factory, but not allocated to storage. According to Strack and Pochet (2010) strategic decisions set boundaries for tactical and operational decisions.

The next step in the incoming goods process is to deliver the articles to their designated storage locations. The results from the ERP gathered data is illustrated in Figure 4.12 and shows the amount of data points within one hour long time spans.
Figure 4.12 illustrates that 32.63% of the incoming goods are confirmed in their storage location within the first five hours after being allocated their storage location. After 24 hours 84.45% of the material is confirmed in their allocated storage. This results in an average lead time for the process of 21.99 hours when analyzing the entire set of data.

As in the previous graphs resulting from the ERP data, a few distinct peaks can be observed as well as a long tail of infrequent measurements. To focus on the peaks and analyze the most common interval of the process, the long tail was removed. The result can be seen in Figure 4.13, which includes 97.17% of the data points.
In Figure 4.13, the average time from space allocation to confirming the article in storage drops to 18.45 hours. Just like the previous sub-process from receiving goods to allocating the storage space, a big difference in average time can be observed when removing the tail of outliers. This is an indication of a process with low precision.

Regarding the two measured sub-processes of the incoming goods process, it can be seen that delivery to storage location has a substantial longer lead time. Hence, it can be argued that it is of greater importance to the overall lead time of the entire process. However, the time between goods received and storage allocation is a waste, which should be removed according to the LM principles (Green et al., 2010; Petersson et al., 2010; Liker, 2004). Hence it should not be ignored and it might be addressed through strategic change. For instance, a policy where goods are received and allocated storage space at the same time would reduce the measured times.

### 4.2.2 Results from Empirically Collected Data

In addition to the ERP gathered data, empirical investigations were conducted to show the causality of various processes. The results from the investigation are shown in this section and are divided into the incoming goods process and the material replenishment process. These are illustrated and explained separately in this section.

#### Material Replenishment Process Results

During the investigation of the material replenishment process the times spent picking, delivering and administrating were measured. In addition, the effects of the emergency phone were observed.

The average time for one picking round was 51.82 minutes. Different pickers were observed taking different amounts of picking orders with them on each tour. Hence, the average time spent picking per article is of interest and was measured to 1.90 minutes.

Furthermore, a difference between picking in paternoster storage and rack storage was observed. Except for the person holding the emergency phone, a mixture between picking in paternoster storage and rack storage was observed for most picking rounds. Since the picker with the emergency phone only conducts rounds in the paternoster storages, these were generally left to that person and the rest picked mainly in rack storage. For pickers that were not on emergency phone duty, an average of 69.7% of the orders were picked in rack storage and 30.3% in paternoster storage.

A difference between picking times for these two storage types was observed. On average, time spent picking per article in the rack storage was 1.73 minutes and 1.10 minutes in the paternoster storage.

Regarding the delivery time to the assembly line, an average of 13 minutes was recorded for the order pickers. This resulted in an average delivery time per article of 31 seconds.

The final step of this process is to confirm the deliveries, which is done by scanning a barcode for each picking order. The average time to finalize this step of the process was measured to 1.90 minutes, resulting in an average time per article of 4 seconds.
All together the observed picking process, from the moment a picker takes the picking order to confirmation was measured to 65.22 minutes. This results in an average time per article of 2.47 minutes. Figure 4.14 summarizes and illustrates the total lead times measured for the material replenishment process.

The secondary flow of the emergency phone occupies one person each day. The average time spent from receiving the phone call to delivering the articles to the assembly line was 6.38 minutes. Most of the times only one article was delivered, but in some instances more were ordered resulting in a average time per article of 5.93 minutes. Furthermore, it was observed that the number of calls varied greatly between days.
Correlation and Causality of Material Replenishment Results

In this section, the empirically gathered results described above are combined with the ERP gathered data. The section explains and analyzes the results further and describes data correlation and data causality. When analyzing the material replenishment process it can be seen that the overall lead time after eliminating outliers was calculated to 11.96 hours according to the ERP data. This time included the time for administration, picking time and delivery time measured during the empirical testing. However, the time between printing the lists and until the picking sequence was initiated could not be measured during the empirical tests.

As observed in the empirical tests, the sequence with the longest average lead time was the picking sequence. This is true both for the total time as well as for the average time per article. This is not surprising as Strack and Pochet (2010) describe picking as often representing the majority of costs and workforce assignment of the inventory management processes. However, this goes against the findings of the ERP data, where it was shown that the time spent before printing accounted for the majority of the lead time. This difference can be explained by the fact that the stock-outs affected the time before printing in the ERP data, but that the same time could not be observed or measured in the empirical tests. During this sub-process, manual handling was observed during the empirical tests. Also, there was no system support to ensure that correct products were picked or placed in the correct storage location. This raised the questions of potential quality issues from picking wrong articles, missing orders and misplacing articles. This observation was confirmed during the interviews as it was said that:

"We only have visual controls today. That’s probably a big reason that we put items in the wrong bin, that we have inventory balance issues, and that we don’t know where our inventory is" - Interviewee 2

"If we are talking about the system, we do not have any support there, at least not for the material replenishment there is no full system support. From the moment that an order is placed at the assembly line till when we deliver it, there is no logic at all" - Interviewee 3

Furthermore, the average time per article between different measurements varies between 1.03 minutes and 3.50 minutes. This might partly be because of varying amounts of picks in rack storage and paternoster storage, since they have different average picking times per article. Another possible explanation is that the case company lacks system support for setting the optimal picking routes. This leaves the pickers to select their own routes, which can lead to varying results. There are potential gains for the case company to reduce travel distance and travel time through the use of optimal picking routes as described by Roodbergen and de Koster (2001). Pickers’ routes vary from time to time and one major reason for this is the lack of system support. The pickers did not know if a storage location was insufficiently filled prior to them arriving at it. Hence they at times had to divert from their route to go to another storage location. If system support would allow workers to know which storage location was sufficiently filled to complete their pick, an optimal route could be calculated and the waste of diverting to another storage location could be eliminated.

These observed variations in picking times during the empirical could also explain the
variations observed in the ERP data. However, the variations observed in the ERP data are much greater and therefore cannot solely be explained by varying routes by the pickers. Rather, this confirms that there are data points present that do not coincide with the normal state observed during the empirical tests.

Another interesting aspect with the empirical test was the observation that as the workload for the material replenishment unit grew, the lead time became longer. The unit could not keep up with the incoming orders and therefore the amount of emergency phone calls increased. This in turn hindered the person with the emergency phone from performing his or her normal picking round, creating an even bigger backlog. This is illustrated by the average picking round for the person with the emergency phone being 2.42 hours when calls were received and only 1.03 hours when no calls were received.

**Incoming Goods Process Results**

The second process investigated was the incoming goods process. Due to the amount of material and relatively long throughput time from goods received to storage space allocation, that process could not be measured. Instead, ERP data was used to estimate that time.

The first step of the incoming goods process is to receive the goods and register their arrival in the ERP-system. As shown in Figure 4.15, it took on average 3.53 minutes to check in each package of articles. Since some packages contained many different articles, the average time spent per article is only 1.72 minutes.

Thereafter, the article is placed on a conveyor belt, which takes it to the next work station. There a storage space was allocated. On average the article spent 4.49 hours between being received and getting a storage space allocated according to the ERP data.

Giving an article a storage location is a rather quick process. It took on average 40 seconds per article. However, the average time after allocating a storage location to confirming that it is in place took on average 43.95 minutes.
Correlation and Causality of The Incoming Goods Process

When comparing the empirically gathered results previously mentioned with the ERP data and interview results previously presented some interesting findings can be observed.

First of all, the sub-processes of receiving goods and allocating storage are performed quickly. The average lead times are 1.72 minutes per article for receiving goods and 40 seconds for allocating storage. However, the average waiting time between the two sub-processes was 4.49 hours for the normal case according to the ERP data. Comparing these numbers, it can be seen that only 0.89% of the time from the initiation of the goods received process to storage allocation is spent on active work. As previously stated, the time between receiving goods and assigning storage can be seen as a waste according to the LM principles (Green et al., 2010; Petersson et al., 2010; Liker, 2004). Another problem caused by the current system is that a lot of material is held up in the goods received unit. This issue is echoed by Interviewee 2 who claims:

"We have way too much material stored at the goods received unit." - Interviewee 2

A second remark is the difference between the delivery time observed in the empirical
tests and the time between storage allocation to confirmed in place from the ERP data. In the empirical test, the actual delivery time from that a cart was transported from the goods received unit till after it was emptied and all articles were confirmed delivered was measured to 43.95 minutes. From the ERP data the average time in the normal case from storage allocation to confirmed in place was measured to 18.45 hours. The difference can partly be explained by the time an article spends "waiting" on the cart after storage allocation and before the delivery route is initiated not being included in the empirical test. However, the observed delivery time is attributed only to 3.97% of the average time resulting from the ERP data. This implies that there is a lot of non-active time during this sub-process. Another reason for this difference might be the fact that articles can be left on the cart over night, dragging up the average lead time of the ERP data.

Literature stresses the positives of effective routing (Roodbergen and de Koster, 2001). However, only 3.97% of the total time between storage allocation to confirmed in place at the case company was spent on actively transporting the articles in the factory. This limits the effect of effective routing on reduction of the overall lead times. There are other wastes that need to be removed, in the form of non-active "waiting" time. This is observed as more important when it comes to reducing the total lead time of the process.

4.2.3 Summary of Factors Driving the Lead Times

The previous sections explained and analyzed results for factors driving the material replenishment lead times. This was done by first explaining and analyzing the results from the ERP data and then combining these results with the results from the empirically gathered data. The purpose was to show the correlation and causality of factors influencing the material replenishment lead times.

The ERP data showed a wide spread of measured values, which can partly be explained by system errors. Outliers were eliminated in order to achieve a more accurate representation of the material replenishment system. This resulted in a total average lead time of 49.25 hours. When broken down into sub-processes, it could be seen that the major part of this lead time was spent from the time the assembly lines placed an order till the orders were printed by the material replenishment unit. This time was measured to 32.51 hours when outliers were eliminated, and can partially be explained by stock-outs preventing orders from being printed until the material has been resupplied in the warehouse. This process can take up to 30 days. The picking process, which was viewed as an issue internally at the case company however only had an average lead time of 11.96 hours. That a process which represented 24.30% of the overall lead time was illustrated as a major issue by internal stakeholders was deemed as telling of the lack of clear information on the material replenishment system.

Regarding the incoming goods process, which also is a part of the material replenishment system, the analysis of the ERP data showed that there is room for improvement. The time from goods received to allocation of a storage location was on average 4.49 hours in the normal case. This entire process can be seen as a waste in the form of waiting according to Petersson et al. (2010); Hicks (2007). The following step of the process was the delivery to storage location, which was measured to an average of 18.45 hours after eliminating outliers. Hence, this process makes up for the majority of the total lead time.
CHAPTER 4. RESULTS AND ANALYSIS

of the incoming goods process, but since the time between goods received and storage allocation is essentially a waste, it cannot be ignored and has to be addressed.

When these results were combined with the empirically gathered data, other discoveries were made. Regarding the material replenishment process, the picking sequence accounts for the majority of the active time (from the lists being printed to the order being delivered), which is in line with prevailing theory. The times per article varied greatly between measurements, showing that the process can be made more efficient and accurate. Overall, a low degree of system support was identified as a major reason for the long lead times.

Regarding the incoming goods process, a 4.49 hour waiting time was observed between two processes that themselves only take 1.72 minutes and 0.67 minutes to complete. This was identified as a major waste. Essentially, this implies that only 0.89% of the total time spent can be classed as active. The long waiting time can partly be due to overnight storage on the conveyor belt, but even so it still accounts for a disproportionate part of the total time.

There was also a big difference in the recorded delivery time in the ERP data and the empirically gathered data. This difference can partly be explained by waiting times not being included in the empirical data. This waiting time could consist of overnight storage and time between storage allocation and initiation of the delivery process. However, since only 3.97% of the average delivery time measured in the ERP data corresponds to active time in the empirical data, it is clear that there is an abundance of waiting time in the processes. Hence, the wastes associated with waiting was identified as the main driver of lead times in the incoming goods process.

4.3 The Effects of Traceability

Subsection 4.3.1 describes the scanning project to set the context for the rest of the section. Then, the direct effects of the scanning project are analyzed. Thereafter, indirect effects of the scanning project on lead times are explored.

4.3.1 Description of the Scanning Project

The scanning project implemented barcode scanning on a wider scale throughout the factory. It entailed replenishment workers carrying a hand-scanner and using it to log their daily work.

Below follow main points with the new work procedure:

- Lists are not printed as before, but are updated automatically and displayed in the hand-scanners
- Instead of using paper lists to handle picking orders, the picker logs in to a storage location and can see the picks for that specific location.
- Items are confirmed picked and delivered in real-time by scanning a barcode instead of after the completion of a picking round.
The points stated above have lead to an increased traceability in the material replenishment system. Users are now differentiated in the system, orders are confirmed in real-time and additional control points have been added to the system. It is therefore possible to know who has done what and at what stage an order currently is in the material replenishment system.

### 4.3.2 Direct Effects of the Scanning Project

The following section describes the difference in lead times between the data presented in Section 4.2 and the data generated from the ERP-system after the implementation of the scanning project. The results are first presented, and thereafter analyzed using both theory and data from Section 4.2.

#### Overall Lead Time

Figure 4.16 shows that the majority of articles ordered by the assembly lines are replenished within the first 24 hours. This results in an overall lead time for the new process of 23.61 hours, possibly since there are no data points of over 30 days. As previously stated, 30 days is the average delivery time from suppliers after a stock-out. Therefore, the data presented in Figure 4.16 can be seen as a representation of the normal case.

A decrease from 49.25 hours to 23.61 hours was observed when comparing this overall lead time to the one calculated in the current state. This decrease in total lead time was to be expected in part due to the lower frequency of data points of longer time-spans. A slight decrease in the frequency of outliers was expected, since the increased traceability has been observed to lead to less uncertainty and a better adjusted process in other studies. This is supported by Dai et al. (2012) who claim that the reduction of uncertainty is one of the main reasons for traceability and by Fang et al. (2013) who claim that traceability
allows for better-informed decisions. This would in turn imply a more stable and precise process.

Even though slight lead time reductions were expected, it was surprising that the overall lead time was cut by as much as 47.94%, due in part to the limited indications of a connection between traceability and lead times in literature. If such big cuts could be made by increasing the traceability of a system, it would be expected that more studies would exist within the specific area. However, in this specific case, parts of the cut in lead time has to be attributed to the changes performed to the process as a byproduct of the scanning project.

In the following sections, the overall lead time is broken down and the parts analyzed separately.

**Time from Order to Start Processing**

As previously mentioned, the process between the assembly lines ordering an article and the material replenishment unit beginning to process the order has changed. Hence, investigating these lead times after the implementation of the scanning project is of interest. The results from the data gathered from the case company’s ERP-system are presented and analyzed in this subsection.

![Data Points Observed](image)

**Figure 4.17: Time spent before handling after traceability project**

The vast majority of data points in Figure 4.17 can be found within the first hour of the process. This is to be expected, since the new process states that the orders are exported to the scanning devices for handling every 15 minutes. Hence, the only orders that are left longer in the system are the ones where no material is present in the warehouse. These orders are exported to the scanning units first when new material has entered the warehouse. Since the average delivery time from suppliers is 30 days, all data points found within 30 days can be seen as the normal case. In the ERP data gathered for this...
investigation, no data points that exceeded 30 days could be found and therefore it can be seen as a representation of the normal case.

The average time spent before starting to process an order is 4.71 hours in Figure 4.17. This implies a 85.51% decrease of lead time compared to the process employed before the introduction of the scanning project. The scanning project has lead to major changes to the working process between order placement by the assembly lines to the start of order handling by the material replenishment unit. In the context of lean, the new process has been improved by removing elements of waiting as well as reducing the amount of over-processing as described by Petersson et al. (2010); Ramesh and Kodal (2012); Chakravorty (2010); Hicks (2007). Hence, the performed changes and the removal of wastes from the system are an improvement in line with prevailing LM principles (Green et al., 2010; Hines et al., 2004; Petersson et al., 2010).

It is difficult to distinguish the extent to which the decrease in lead times can be attributed to the increase in traceability. The majority of the reduction could stem from the changes to the actual processes rather than the increase in traceability. However, the introduction of barcode scanning and the increase in traceability reduced the risk for manual processing errors, which was described as an issue in the process utilized in the old current state. For instance, interviewee 6 highlighted that the use of paper lists was an outdated, time consuming and error strewn way of handling transfer-orders.

"I think it is an outdated method to handle transfer-orders (lists)… to do so on paper that then have to be sorted." - Interviewee 6

The reduction of potential error sources within the process could imply that the amount of outliers are reduced. This would in turn reduce the average lead time of the process. This is supported by Han et al. (2011), who claim that the introduction of barcodes reduce the risk of manual data errors and by Lee and Özer (2007), who claim that the increased traceability would decrease the presence of inventory discrepancies. This could in turn reduce the amount of stock-outs, which would reduce the average lead time. However, in order to be able to irrefutably claim that the increase in traceability lead to a decrease in lead times, the set of data investigated would have to be larger and traceability separated from simultaneous process improvement work.

**Picking and Delivery**

After the implementation of the scanning project the process of handling the orders can be divided into time spent picking and time spent delivering. However, for this analysis they are investigated together to aid comparison with the results described in Section 4.2. In the following section, the picking and delivery results from the ERP data gathered after the implementation of the scanning project are described and analyzed.
The majority of the data points in Figure 4.18 are found within the first 24 hours of the process. This results in an average time from the initiation of the picking process to confirmed delivery to assembly lines of 18.90 hours for the entire set of data. Distinct similarities regarding distribution of the data points can be seen when compared to the overall lead time presented in Figure 4.16. Since the shape of the graph illustrating the total lead time is very similar to this part of the process, it is an indication of the importance of the picking and delivery process to the overall lead time. Furthermore, 18.90 hours is the majority of the overall lead time, which further strengthens this assertion. This is in line with Strack and Pochet (2010), who claim that 65% of the costs and 50% of the workforce of the warehouse is oftentimes directly associated with the picking activity.

Since orders that are not picked during the same day as they are exported to the scanning devices are dealt with first of all the day after, the normal state at the case can be said exist within the first 32 hours of the process. This is also visible in Figure 4.16, where two distinctive peaks can be observed. The normal state is illustrated in Figure 4.19.
When analyzing the normal state of the process, an average lead time from the initiation of the picking process to confirmed delivery of 12.83 hours was observed. When comparing the results from the "old" current state described in Section 4.2, similarities in the spread of data points can be seen. This illustrates that the process itself has not been changed drastically. However, the average lead time observed in Figure 4.19 is higher than for the same time before the implementation of the scanning project. This can partly be explained by the employees not having more than four weeks to learn the new process prior to collecting the data. This could imply that the average lead times are slightly higher than what they would be if the data would have been collected at a later point of time when the process had been learned. This is supported by Glock (2012), who claims that the time needed for a process decreases as the changes mature. Even though Glock (2012) draws this conclusion from a pure production process, the authors present no evidence as to why this should not hold true for other processes as well. As the project matures and the pickers learn the process, the picking and delivery times will naturally decrease. Further, an additional step has been added to the process which suggests that some time could be added to the overall lead time. However, the entire 0.87 hours difference cannot be accounted for by this change.

Figure 4.20 illustrates the new material replenishment process used after the implementation of the scanning project. This shows the interdependency of the various sub-processes, and illustrates where in the overall process the different lead times analyzed above are found.
4.3.3 Indirect Effects of the Scanning Project on Lead Times

The scanning project incorporates the widespread use of hand-scanners, but also increases the traceability in the replenishment system in a number of different ways. Users are differentiated, an additional control point has been added, and real-time confirmation is now possible. These improvements were not directly observed to reduce the lead times as in Section 4.3.2, but could contribute to a reduction of lead times indirectly as the project matures and the implementation stabilizes.

The scanning project differentiates between the users of the hand-scanners, meaning that data can be collected for each replenishment worker. This means that mistakes can be picked up on, improvement areas more easily identified, and performances assessed. This should provide the case company with data that allows for the reduction of lead times through an improved standardization of the process. This is supported by Fang et al. (2013); Dai et al. (2012), who claim that the increased availability of real-time data as a result of increased traceability allows for better-informed decisions.
The implementation of the project has added an additional control point in the process, evidenced by the new data set generated from the ERP-system. The control point splits the time from lists printed to delivery into picking and delivery, which again is a source of information as to which parts of the process are inefficient and can be improved upon. Lee and Özer (2007) argue that readers or control points are as important to achieving traceability as the actual technology used. Their findings are consistent with findings in this study. The data collected, like information on which worker was involved in an error, can serve as a basis to reduce complexity and increase information sharing according to both de Treville et al. (2014); Bellamy et al. (2014). This has been studied extensively, and a general consensus exists that indicates a strong possibility of reducing lead times by adding control points and clarity to the processes.

The new hand-scanners allow for real-time confirmation of goods movements in the warehouse. For instance, articles delivered from the main storage to the kitting storage by the assembly line is now confirmed as soon as it is delivered. Hence the previous delay between the delivery of an item and the confirmation that the item has been delivered is removed. This improvement does not directly reduce the lead time experienced by the internal customer (the assembly lines) but it does have an effect on the lead time as logged by the ERP-system. Real-time confirmation of orders and picks prevent overlaps between workers and confirm that orders have been delivered, removing uncertainty.

The addition of extra control points as well as real-time confirmation makes it harder for the employees to make errors such as misplacing articles or picking the wrong articles. The additional system support and real-time feedback to the employees allows them to discover errors directly and to correct them at once. This allows for higher overall quality due to minimization of errors as well as potential shortening of the lead time due to improvement of the process and elimination of outliers.

4.3.4 Summary of the Effects of Traceability

In this chapter, the effects of the increased traceability on lead times as a result of the implementation of the scanning project were described and analyzed. The project itself changed some processes in the system and implied that users could be differentiated, orders were confirmed in real-time and that additional control points were added in the system.

In order to investigate the effects of increased traceability on material replenishment lead times, ERP data was gathered from after the implementation of the scanning project at the case company. The direct effects of this project included a 47.94% shorter overall lead time, a 85.51% decrease in time spent between order and start of order process and a 7.27% longer order handling time. To what extent these improvements are a direct result of an increased traceability is debatable. Parts of the improvements were a result of new, improved processes rather than an increased traceability. For example, the big decrease in time from order placement to the start of order processing is mainly accounted for by a process change to reduce waiting. However, traceability can be part of the lead time reduction since potential sources of errors appeared to have been reduced.

In addition to direct effects, some indirect effects of the scanning project on material replenishment were observed. The system now differentiates between users, which means
that mistakes can be picked up more easily and the workers presented with individual improvement plans. The addition of control points allows for more information-gathering. This information can in turn be used to reduce the complexity of the system and increase the information sharing. Real-time confirmation of goods movements in the warehouse reduces the lead times experienced in the ERP-system by preventing overlaps between workers. Orders can quickly be confirmed as delivered, removing uncertainty.
Chapter 5

Conclusions

In this chapter the study’s conclusions are presented and described. Each research question is answered separately, eventually leading to an answer to the main research question of the study. Further, theoretical and managerial contributions are considered and discussed. Finally, the sustainability perspective of the results as well as limitations and proposed future research are discussed.

5.1 Conclusions - Research Questions

RQ 1: What is the current state of the material replenishment system?

The first phase of the research was to conduct an investigation on the state of the current replenishment system at the case company, including mapping processes and understanding the major flows. This was done by walking the process and through interviews with key stakeholders.

The case company uses a shared storage strategy to maximize space utilization, meaning that items can be stored at multiple, different locations within the warehouse. Further, the local storage by the assembly lines utilizes a 2-bin Kanban system, meaning that when one bin of articles is spent another one is ordered and that the second bin acts as safety stock until the refill has been made. It is also important to note that articles are not picked to exact quantities, rather items are picked in bins deemed to contain a relevant stock level. Lastly, another characteristic of the current material replenishment system is that stock balances are only monitored when entering the factory and when leaving, and there are no control points between these two steps. The above factors, along with a varied, complex product portfolio, has lead to high inventory levels.

Operational strengths and areas of improvements identified with the current inventory replenishment setup are listed below.

Operational Strengths

• Local stock-outs rarely cause a stop in assembly operations due to safety levels
• Space utilization can be considered high for current setup

Areas of Improvement

• Capital intensive system with capital bound in stock
Processes that are difficult to visualize, and described as "confused" or "outdated" by internal stakeholders

- Presence of LM wastes throughout processes, masked by high levels of inventory
- Agreement on key problem areas by key stakeholders, but disagreement and feelings of hopelessness over potential solutions

A significant potential for improvement of the current state and its processes was discovered.

RQ 2: What factors are driving inventory replenishment lead times?

The investigation of drivers of lead times consisted of an analysis of ERP data gathered from the case study as well as empirical testing. The observed total average lead time for the entire set of data was 99.78 hours and after eliminating outliers the lead time was measured to 49.25 hours. In the following section, the total lead time is broken down and key drivers identified.

Material Replenishment

The material replenishment process itself consists of two sub-processes; time before printing and time spent picking. The majority of the total lead time for the normal case, 32.51 hours, was spent before printing the order lists. The picking time was only 11.96 hours. Below, factors that caused high lead times are listed:

- Unstable processes causing many outliers that drive the average lead time up.
- Lack of system support for optimal routing causes different picking speeds for employees.
- Stock-outs causes waiting time, which increases the average lead time.
- Increased workload causes overload, which causes increased lead times.
- Inefficient processes cause unnecessary waiting time.

When investigating the above factors, the waiting time as a result of stock-outs and sub-optimal processes was identified as the major driver of lead times at the case company.

Incoming Goods

Regarding the incoming good process, the majority of time, 18.45 hours for the normal case, was spent between storage allocation and until the article was confirmed in place. The other sub-process between incoming goods and storage allocation only accounted for 4.49 hours. The most important factor driving lead times in the incoming goods process was waiting time. This waiting time was caused by the following issues:

- Inefficient processes
- Cumbersome material throughput rate

The waiting time described above could be removed by assigning the storage location directly after receiving the goods instead of first receiving all goods and then assigning the storage. This would imply that the throughput time per article from goods received to storage allocation would decrease. However, since the receiving goods process now
includes storage allocation, the frequency at which goods can be received would become lower. Still, the increased throughput rate implies that fewer articles would be held up in the incoming goods area and that articles would go from receiving goods to confirmed in storage quicker due to eliminated waiting times.

Overall, the most important factor for drivers of lead times when investigating all sub-processes was the waiting time in the system.

**RQ 3: How does traceability affect the material replenishment system?**

After the implementation of the scanning project, which increased the traceability of the material replenishment system at the case company, some changes to the average lead times could be observed. These changes were:

**Material Replenishment**

- Overall lead time decreased from 49.25 hours to 23.61 hours.
- Time between order placed by assembly line to start of order handling decreased from 32.51 hours to 4.71 hours.
- Order handling time (picking and delivery) increased from 11.96 hours to 12.83 hours.

The above effects were referred to as "direct effects" of the scanning project. In addition though, the project had other more indirect effects that could be related to the increase of traceability. These effects were:

- Users can be differentiated in the system, allowing for better error tracing and employee development.
- More control points were added, implying that more accurate data can be gathered from processes and used for improvement work.
- Picks are confirmed in real time, resulting in an updated system that prevents overlaps.
- System support for pickers hinders misplacement of articles.

The above state effects have created a more visible system, where it is easier to see who has done what and where articles are through the use of the ERP-system.

**Main RQ: How does increased traceability within the material replenishment system to multi-product lean assembly lines affect the lead times?**

The answers to the above sub research questions indicate that there are numerous improvement areas within processes and various possibilities to decrease the relatively long internal lead times. The implementation of the scanning project allows for conclusions to be made regarding attempts to increase traceability in an internal factory logistics setup.

This specific investigation was conducted in a material replenishment system characterized by high stock levels, outdated processes, and low visibility in the ERP-system. Internal lead times were found to be driven by a number of characteristics of the process, such as unstable processes, the lack of optimal routing, unequal workload distribution, and queuing and waiting. The case company’s implementation of the scanning project
lead to various improvements, including a marked decrease in waiting time leading to a significant decrease in the total lead time in the process.

Even though the investigation into the effects of an increased traceability on the replenishment system showed some direct effects on lead times, they are inconclusive. The case company’s project to increase traceability led to simultaneous changes in processes and removed several wastes from the system, meaning that the actual effects attributable to an increased traceability cannot be distinguished from other interdependent improvements. There definitely appears to exist a relationship between traceability and internal, factory lead times but the extent of the relationship cannot be concluded upon. Having said that, the study does offer conclusive evidence that traceability is linked to process improvement and that in attempting to increase traceability, other improvements can result as byproducts.

These improvements were referred to as indirect effects in this study. The most noticeable and important effect as a result of an increased traceability was the facilitation of future decision making through an increased availability of more data. The reasons for the increased data availability in this specific case are listed below.

- Additional stock/item control points within the processes
- Differentiated users of the system allows for information as to which worker is working, where mistakes were made and a plan on how to work with worker improvement
- Real-time confirmation of orders allows for an up-to-date monitoring of the logistics process and for a shift from retroactive to proactive internal logistics
- Real-time confirmation of picks and an increased system support for pickers decreases the risk for errors such as picking wrong articles or misplacing articles.

The above stated factors can reduce material replenishment lead times since the increased number of control points and real-time confirmation of data will aid in future decision-making. This through the availability of more data points that allow the company to identify areas of improvement and take better-informed decisions regarding how to optimize the processes. In addition, the differentiation of users in the system makes it possible to identify and deliver individual feedback to employees not working according to the recommended process. This approach will improve the workforce and might also lead to reduced lead times.

All together, these factors will help the company in creating more stable processes, aid the employees in doing things right and eliminate unnecessary wastes such as waiting and queueing. All of these are aspects that when reduced can reduce the material replenishment lead times. Hence, even though no direct effects could be proven, the indirect effects of an increased traceability can lead to lower lead times.

5.2 Theoretical Contribution

The conceptual contribution for this study lays within the field of CIM and investigates the effects of an increased traceability on material replenishment lead times. The fields of Traceability and shortening of lead times have previously predominantly been separately
investigated in academia. The study attempted to address this gap in literature by investigating whether a relationship between the two exists.

The study confirms theories claiming that traceability is not in itself a value-adding operation, but still a necessary one, such as Cheng and Simmons (1994). In the study no clear direct effect on lead times could be shown from an increased traceability. However, the potentials of traceability as a tool for continuous process improvement was observed. This is in line with Cheng and Simmons (1994) and also Dai et al. (2012), who claim that increased traceability allows for better-informed decisions. Essentially the study identified potential, indirect effects on lead times due to an increased traceability rather than a direct relationship.

The study can be seen as an investigation of how an increased traceability can be used in order to adjust a material replenishment system to lean assembly lines. The reason for this is that the principles of continuous improvement in lean are positively supported by the increased availability of real-time data. Issues can be addressed and the root-cause can be investigated quicker as a result of this. Therefore the study confirms the theory of Dai et al. (2012), who claim that traceability can facilitate the implementation of more advanced manufacturing strategies. However, in the context of LM, the addition of extra control points can be seen as a sort of over-processing since it adds no direct value. The study therefore shows that there might be operations that are classified as waste according to lean principles, but still should not be eliminated since they facilitate future improvements to the entire system.

The final theoretical contribution of the paper is that the study provides an initial attempt at outlining the relationship between traceability in an internal material replenishment setup and order completion lead times. Whilst the results are not conclusive enough to ascertain that there is a relationship, neither are they conclusive enough to discard a relationship.

5.3 Managerial Contribution

In addition to the theoretical contribution of the study explained in Section 5.2, the study also has various managerial contributions. These include recommendations on how the findings in this study can be implemented within a business.

The results from this research show that the case company could benefit from further increasing the traceability in the material replenishment system. The increased amount of control points and real-time data allows for better-informed decisions to be taken, such as for improved processes, stock levels and prognoses. It is important to understand the process and what areas can be improved in order to improve the process and achieve a material replenishment system that is custom-fit to the rest of the business. Further, an increased traceability can facilitate the implementation of lean logistics and other advanced systems to implement a logistics system that suits the lean assembly lines. Hence, increasing the traceability of the system is recommended in the case company’s continuous attempt to implement LM in the assembly lines’ support functions.

It is important to understand that increasing traceability does not automatically lead to reduced lead times for the material replenishment systems. Rather, it aids the business
in taking steps to improve the processes and thereby decrease the lead times.

This study can be used by the case company to identify areas of importance to their internal material replenishment lead times. Therefore, the results from this research can facilitate and act as a pre-study for their future improvement work on the internal processes. For companies similar to the case company, this research can indicate what areas to start looking at when aiming to improve their business.

Furthermore, the implementation of the scanning project at the case company, increasing the traceability in the system, has been proven a great success. Hence, this research can be seen as a vindication of the project and can aid in motivating a continuation of the work to achieve a more visible and traceable process in order to improve the material replenishment system and reduce lead times. For businesses that have not yet implemented any similar projects, this research can be an indication of potential effects when implementing such a project but also an outline of which conditions need to be in place for the improvements to be achieved.

The study serves to illustrate the difficulty in starting to work towards reducing lead times in a lean context. It is easy to get blinded by outdated processes that have been in place for a long period of time. For some production companies, getting away from the old processes could prove relatively easy if the system setup allows for data to be collected and analyzed to start potential improvement work. For others, increasing traceability within the process can be a significant first step to make more data available to ensure that the improvement work has a distinct direction and purpose given the current state and its issues and problems.

Specifically for the case company and other similar firms, the above explained managerial contribution can be reduced to a recommendation consisting of five steps.

1. Increase the inventory control by increasing the number of control points in the ERP system.
2. Use the increased amount of data to investigate each article and determine how they shall be handled and set daily prognoses.
3. Make assembly lines order material from material resupply one day in advance, meaning that the production orders have to be set the day before production.
4. Reduce the assembly line storage so that only articles needed for the coming day are being stored there.
5. Supply the assembly lines proactively and use the data gathered through increased traceability to improve processes continuously.

5.4 Sustainability Discussion

According to Gimenez et al. (2012), "sustainability integrates social, environmental and economic responsibilities", which often is called the triple-bottom-line. Below, this study’s influence on these factors is discussed.

This study has analyzed the effects of an increased traceability on material replenishment
lead times. An increased traceability does not have any direct, tangible impact on the environment. Rather, the decisions that can be taken based on the data gathered through an increased traceability can influence the environment. However, since these decisions are not a part of this study, the discussion is not relevant to this study.

Regarding the economic aspect of the triple-bottom-line, producing companies have to strive to always have updated prognoses and control over their own processes. This allows companies to be efficient, competitive and continuously improve their operations. The increased amount of data acquired from an increased traceability has been proven to aid managers in taking well-informed decisions and therefore take actions that improves the organization. Hence it can be argued that an increased traceability will have positive effects on the economic situation of the enterprise.

Also, the increased traceability implies more control over the employees, since errors can be traced back to specific persons. Hence, the company can see in what areas an employee struggles and take measures to help them evolve and develop their skills even further. However, too much traceability might lead to employees feeling monitored, which might increase stress levels and decrease their morale. Therefore, a carefully balanced amount of traceability has to be implemented so that the economic advantages can be acquired without damaging the psychosocial state of the employees.

5.5 Limitations and Future Research

A case study was conducted in order to investigate the effects of increased traceability on material replenishment lead times. The case study was conducted at a producing company’s factory in Sweden. Since only one factory was included in the case study, the results might be case specific and some aspects of similar processes elsewhere might have been missed.

The limited traceability of the case company made it difficult to gather the wanted data from the ERP-system. The sets of data gathered therefore had to be adjusted to what was available instead of what was requested. Furthermore, due to time constraints it was not possible to collect an empirical data set of equal size as the one obtained from the ERP data. At first, this was not considered an issue as the larger set of data was meant to portray the actual lead times, and the self-collected data was meant to describe why the lead times looked the way they did. However, while the self-collected data did describe why lead times were the way they were to some extent, it did not describe all of the reasons exhaustively. Since the collected data was significantly smaller in size, there was a mismatch between the two data sets when the same part of a process was investigated. It was not possible to determine whether this mismatch was due to differences in how the lead times were logged in the ERP-system compared to how they were on the factory floor or if it was accounted for by the difference in the data sample size.

Another limitation of the study is that the measured process underwent changes during the course of the research. As the scanning project was conducted, which increased the traceability of the system, the processes themselves also changed. This implies that it was difficult to investigate what changes in lead times were due to changes to the process or due to increased traceability. It would have been preferred if the only parameter
changed in the system was the traceability. In that case the effects could have been more thoroughly investigated and understood.

A further limiting factor was the time frame of the scanning project. It was implemented during the later stages of the study which made it difficult to acquire the wanted data set. It would have been preferred if the same amount of data was available for the comparison of the "old" ERP data and the "new" ERP data. Due to the smaller set of data in the later stage, the results could have been skewed. For instance, outliers and stock-outs were not present in the same frequency and therefore not driving the average lead times up to the same amount as for the process prior to the implementation of the project, where a larger set of data was used. Also, the data for the system after the implementation of the scanning project was taken from shortly after the implementation itself. This implies that the employees had not fully grasped the changes yet, which might have influenced the results. For example, teething problems might affect the results.

To address these limitations and continue the research within the field, future studies should be conducted. There are aspects of the study that lend themselves to further research.

Future research should look into isolating traceability in a way that was not possible in this study. This would allow for a more detailed understanding of the effects that traceability has on lead times. Further, it could be interesting to understand the overlaps and contradictions between an increased visibility such as that proposed by LM and traceability; is there a point where traceability adds complexity and actually decreases visibility?

Furthermore, the research regarding the effects of increased traceability for the case company used in the study should be conducted again after one year in order to be able to compare equally sized sets of data from before and after the implementation of the scanning project. By comparing the sets of data again when the scanning project has been running for one year, a better understanding of its effects on stock-outs and outliers could be obtained. Hence, this would give a more precise indication of the new lead times.

Lastly, the study should be conducted on additional case objects. This would allow for the investigation of the problem in additional settings and for gaining a more generalizable result regarding the effects of traceability on lead times. Different companies have different processes and different factors driving lead times. A study on other case objects could complement or contradict the results of this study and can aid in the evaluation of how generalizable the results of this study are.
Bibliography


Appendix A

Translated Quotes

Quote 1:
"We only have visual controls today. That’s probably a big reason that we put items in the wrong bin, that we have inventory balance issues, and that we don’t know where our inventory is" - Interviewee 2

Translated from
"Allting är bara visuell koll i dag. Det är nog en stor del till att vi lägger grejer på fel ställen, att vi får felsaldo, och inte vet vart grejerna är."

Quote 2:
"We register the wrong quantity as goods received, we shift materials and place the wrong items in our storage racks and paternoster storage. We lose items, items sometimes never make it to their designated storage location, different items are mixed in the same bin but are registered as the same item." - Interviewee 6

Translated from
"Man godsmottar fel antal, man skiftar materialet så att man lägger in fel grejer i våra verk och paller. Man tappar bort grejer, de kommer inte ens till platsen, man samlägger flera sorter i en pala, man ser inte att det är flera artiklar utan allting åker in som en artikel i ett palla."

Quote 3:
"The ERP-system ensures that the possibility of having an efficient material replenishment system is limited" - Interviewee 1

Translated from
"SAP och möjligheten att få en effektiv materialförsörjning är väl inte så bra"

Quote 4:
"If we are talking about the electronic system, we today lack full system support regarding material replenishment. From the moment an order is
received from assembly till we deliver the order, there is no logic in the system at all."

**Translated from**

"Om vi pratar elektroniska systemet då, där har vi inte support, inte fullt systemstöd idag åtminstone vad gäller materialförsörjning. Från det att det läggs en beställning från montering tills att vi levererar ut, det finns ingen logik i det överhuvudtaget."

**Quote 5:**

"We borrow everything from "virtual." And when we then empty a storage location, then we refill in virtual, so there is always a balance there, but never at a specific storage location." - Interviewee 6

**Translated from**

"Man lånar allting från "virtual". Och sen när man tömmer en lagerplats, då fyller man ju på virtual så det finns hela tiden en balans där "

**Quote 6:**

"It can be deviations from the supplier, differing quantities, quality deviations. These are pure supplier errors. It can also be a component error or a documentation error."

**Translated from**

"Det kan vara avvikelser från leverantörer, antal som diffar, kvalitetsavvikelser. Det är ju dels rena fel från leverantören. Det kan vara på komponenten eller på dokumentationen"

**Quote 7:**

"It can also be purely due to errors from us internally. Inadequate processes maybe, or the fact that we don’t follow the stated processes and things like that." - Interviewee 7

**Translated from**

"Sen kan det ju också vara rena fel från oss internt. Lite bristande processer kanske eller man följer inte uppsatta processer och sånt."

**Quote 8:**

"Things happen, we lose an item here, count items wrong, someone was distracted or entered the wrong input into the system." - Interviewee 8

**Translated from**

"83"
"Det händer grejer, man tappar en kula här, räknade fel, någon störde eller man knappar in fel, sen måste ju också hantera alla lagerplatser"

Quote 9:

"We solve every stock balance fault for the moment, or we actually don’t solve it, we address the fault so we can move on. We don’t solve the problem and we don’t check for the root cause. We have the same type of stock balance fault the day after." - Interviewee 7

Translated from

"Vi löser varje saldofel just för stunden, eller vi löser inte, vi åtgärdar så vi kan gå vidare. Vi löser inte problemet vi kollar inte ens rotorsaken. Vi har samma typ av saldofel på en annan komponent dagen efter, vi täpper aldrig till det."

Quote 10:

"There is very little proactive work being done within the internal logistics setup." - Interviewee 2

Translated from

"Det är väldigt lite proaktivt arbete som försiggår inom logistiken."

Quote 11:

"I think many view stock balance faults as a problem" - Interviewee 8

Translate from

"Saldofel tror jag många tycker är ett problem"

Quote 12:

"Stock balance faults is a problem that the whole factory is aware of, I think." - Interviewee 7

Translated from

"Sen saldofel är ett stort problem som hela fabriken är medveten om tror jag."

Quote 13:

"Stock balance faults is viewed as a problem, but I don’t think that we take it seriously enough, bearing in mind that we have continuous faults." - Interviewee 1
Translated from
"Däremot saldofel ses som ett problem, men som jag sa tycker inte jag att man tar det tillräckligt allvarligt med tanke på att det är så kontinuerligt att vi har saldofel."

Quote 14:
"The feeling I have is that the internal logistics is very inefficient. We repack and pick alot of items." - Interviewee 5

Translated from
"Känslan är att det är väldigt ineffektivt. Vi ser ju att vi plockar om mycket material"

Quote 15:
"Then we are talking about the complexity. Since we haven't changed anything for a long time, that means that if it was an easy fix we would have done it in my opinion." - Interviewee 5

Translated from
"Det är då komplexiteten som vi pratar om. Eftersom vi inte har gjort något på många år, så innebär det att, om det vore enkelt så skulle vi ha gjort det, så känner jag."

Quote 16:
"It takes a very long time to get an efficient logistics setup using racks. You have to drive the truck, lift the material up and down, and you have racks that take up alot of space." - Interviewee 1

Translated from
"Det tar ju väldigt lång tid att få en effektiv logistik med pallställage. Man ska ju köra med trucken och lyfta upp eller ner material, du har pallar som tar mycket plats."

Quote 17:
"You can see that when the amount of work increases, so too does the amount of calls to the emergency telephone. Some find it stressful to be in charge of the phone when the workload is high." - Interviewee 3

Translated from
"Man ser att mängden med jobb ökar och i och med det ökar akuttelefonen. Framförallt akuttelefonen, vissa tycker det är riktigt jobbigt att ha den när det är hög belastning."

**Quote 18:**

"They (the lists) are collected maybe twice a day instead of doing it continuously. That means that we say that we have a 24 hour lead time there and we maybe manage that in most cases." - Interviewee 7

**Translated from**

"De samlar man ju upp kanske 2 gånger per dag istället för att ha ett kontinuerligt arbete där. Det innebär ju att vi säger att man har en ledtid på 24 timmar där och det kanske man håller i de flesta fallen."

**Quote: 19**

"Inventory is a tool used to check a stock level, it is not meant to be used to balance stock" - Interviewee 7

**Translated from**

"Inventering, det är en kontrollgrej, det är inget man ska använda för att balansera ett saldo"

**Quote: 20**

"The time to make a pick takes too long. Both to put material into storage and to pick it out of storage." - Interviewee 1

**Translated from:**

"Tiden för att göra ett plock tar för lång tid. Både att lägga in material och plocka ut det. Det beror väl dels på det där med pallställagen, vi har alldeles för mycket pallställage i förhållande till andra mer effektiva lösningar."

**Quote: 21**

"We are definitely re-picking material very often, transporting it between racks, back and forth actually until it eventually lands in the assembly line." - Interviewee 6

**Translated from**

"Helt klart plockar vi om materialet väldigt många gånger, och flyttar det genom ställ, fram och tillbaks egentligen innan det dimper ner i monteringsgrupperna till slut."
APPENDIX A. TRANSLATED QUOTES

**Quote: 22**

"I think it is an outdated method to handle transfer-orders (lists) and to do so on paper, that then have to be sorted." - Interviewee 6

**Translated from** "Men jag tycker att det är ett gammalt sätt att få ut transferordrar och en grej på ett papper, sen ska det sorteras så man kan hämta det och så alla dessa paper som sticker upp och så ska alla grejer samläggas.."

**Quote: 23**

"I do not think that they work especially efficiently in the receiving goods and material replenishment units. Partly because they do not have the tools, by that i mean technical aids to handle the ERP-system, and partly because the flow has never, or I should not say never, but the flow has not been mapped and investigated for potential improvements." - Interviewee 1

**Translated from:**

Sen så tror jag att de jobbar ganska ineffektivt på godsmottaget och materialförsörjningen. Dels för att de inte har verktygen, alltså då menar jag de tekniska hjälpmedel för att hantera det i SAP och dels för att man aldrig - eller aldrig ska jag aldrig säga - man inte har kartlagt flödet ordentligt och försökt förstå vilka förbättringar man kan göra.

**Quote: 24**

"If we regard that we try to reduce the production lead time to 1-2 days from loose components arriving at the assembly lines to a complete and tested product. Then 24 hours to receive the needed components is horrible" - Interviewee 7

**Translated from:**


**Quote: 25**

"If we are talking about the system, we do not have any support there, at least not for the material replenishment there is no full system support. From the moment that an order is placed at the assembly line till when we deliver it, there is no logic at all" - Interviewee 3

**Translated from:**
Om vi pratar elektroniska systemet då, där har vi inte support, inte fullt systemstöd idag åtminstone vad gäller materialförsörjning. Från det att det läggs en beställning från montering tills att vi levererar ut, det finns ingen logik i det överhuvudtaget.

Quote: 26

"The technical solution in the ERP-system does not allow for us to pick efficiently... The internal customer suffers." - Interviewee 1

Translated from:

"Den tekniska lösningen i affärsystemet möjliggör ju inte att vi plockar effektivt... den interna kunden lider"

Quote: 27

"Traditionally we have been working with high safety stock levels to manage the fluctuations instead of working with the system to achieve an even flow throughout." - Interviewee 4

Translated from:

Traditionellt jobbat med stora säkerhetslager för att klara av dessa svängningar istället för att jobba med system för att få ett jämnt flöde hela vägen

Quote: 28

"This implies that we hide many of our problems I think, because when we build up our stock levels many of the problems are hidden." - Interviewee 1

Translated from:

Det gör att vi gömmer många problem tror jag, för när vi bygger upp stora lager så döljs många av problemen.

Quote: 29

"We have way to much material stored at the goods received unit." - Interviewee 2

Translated from:

Vi har alldeles för mycket material lagrat på godsavdelningen.
Quote: 30

"Somehow we have to work with managing and reducing our storage parameters gradually together with working with the internal logistics" - Interviewee 1

Translated from:

"På något sätt måste man jobba successivt i samband med att vi styr våra lagerparametrar nedåt så måste vi jobba med den interna logistiken" - Interviewee 1
Appendix B

Interview Questions

The following interview questions are formulated in Swedish as the interviews were held in Swedish.

Inledning:

• Berätta vilka vi är och vad vi gör
• Berätta vad vi ska göra med materialet - i.e. transkribera, skicka till de för godkännade
• Berätta att de kommer vara anonyma i rapporten
• Får vi spela in?

Inledande Frågor

• Vad har ni för jobbtitel?
• Vad har ni för arbetsuppgifter?
• Hur kommer ni i kontakt med materialförsörjningen / interna logistiken?
• Vad är din roll i materialförsörjningssystemet?

Generala frågor - Current State

• Ser ni några problem med dagens system?
• Hur upptäckte ni dessa problem?
• Tror ni att många ser detta som ett problem?
• Vad tror ni är orsaken till dessa problem?
• Hur tror ni att man kan lösa dessa problem?

Interna ledtider

• Vilka processer tror ni driver upp ledtiderna i dagens system?
• Pratas det mycket om dessa problem?
• Hur påverkar detta ert dagliga arbete?
• Är det många som delar era åsiker?
• Hur kan man lösa detta?

Saludofel
• Finns det mycket saldofel i dagens materialförsörjningssystem?
• Om ja: Kan ni utveckla varför ni tycker det?
• Om nej: Varför är ni av denna åsikt?
• Vad tror ni är anledningen till detta?
• Är det många som ser detta som ett problem?
• Vad tror ni man kan göra för att lösa problemet?

Positiva aspekt - Current State
• Vad fungerar bäst i dagens system?
• Varför tycker du det?
• Hur påverkar detta ditt arbete?