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## **MASTER'S THESIS**

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# Abstract

The purpose of this thesis has been to explore how to effectively manage a warehouse using concepts from Lean and Six Sigma. Using a warehouse in Dusavik, Stavanger as a basis for the case study, it looks at the challenges faced by the warehouse.

Through the case study, observations and interviews have been sources of information to understand the warehouse functions and challenges. Current theory on warehousing and Lean forms the theoretical framework, which is linked and related to the observations.

A foundation combining the identified challenges and theoretical solutions is created, from which a discussion is spawned. The discussion addresses implementation and affected processes, in addition to providing recommendations on tools to improve warehouse processes. The key recommendations are in the form of 5S, planning and scheduling through kanban tools, and standardized processes.

Furthermore, bottleneck processes are identified, their effects are outlined and discussed, and some recommendations are provided on how to elevate the bottleneck constraint.

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# Acknowledgements

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Stavanger, 15.06.2015

Henrik Christiansen

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# Acronyms

**APR** adjustable pallet racking.

**DMAIC** Define-Measure-Analyze-Improve-Control.

**ERP** Enterprise Resource Planning.

**FIFO** First-In-First-Out.

**GE** General Electric.

**GR** goods received.

**JIT** Just-In-Time.

**KPI** key performance indicator.

**LIFO** Last-In-First-Out.

**NNVA** necessary non-value adding.

**NVA** non-value adding.

**PO** purchase order.

**QC** quality control.

**QI** quality inspection.

**SKU** stock keeping unit.

**TPS** Toyota Production System.

**VA** value adding.

**VSM** Value Stream Mapping.

**WBS** work breakdown structure.

**WIP** Work-In-Process.

**WMS** warehouse management system.

**XT** christmas tree.



# Chapter 1

## Introduction

### 1.1 Background and purpose

This thesis is written and based on an actual warehouse in Dusavik, Stavanger, belonging to General Electric. The particular warehouse has problems with delays, and while a new, larger and more modern warehouse is under planning (construction is scheduled to start when this thesis is delivered), the current warehouse will still be operational for some time.

The thesis aims to explore and identify how the warehousing operation can be improved using concepts and ideas from Lean and Six Sigma. The goal is to achieve insight into the tools and ideas that can be used, based on the current state in the existing warehouse. Some of the findings and recommendations from this thesis may also be relevant for the new warehouse.

#### 1.1.1 General Electric

General Electric (GE) was founded in 1892 when the Edison General Electric Company (in turn founded by Thomas Edison) and the Thomson-Houston Electric Company merged. Since then, GE has grown to become a publicly traded conglomerate with over 300,000 employees, ranking amongst the top Fortune 500 companies both by gross revenue and profitability. GE consists of multiple divisions, spanning from aviation to health care.

GE Oil & Gas is one of the larger divisions of the GE conglomerate, with over 45,000 employees worldwide. GE Oil & Gas has approximately 400 employees in Stavanger, and provides drilling solutions, offshore solutions and subsea solutions. Some of the products supplied by GE include "christmas trees (XTs)", control and manifold systems and well-heads (*GE internal resources*).

## **1.2 Problem description**

The main goal of this thesis is to identify what makes a specific warehouse inefficient, and how these inefficiencies affect the operational aspects of the company. Furthermore, it will aim to propose solutions to create a more efficient, Lean warehouse. This will be done in a context of Lean and Six Sigma, using concepts and the philosophy from Lean combined with the data-driven analysis from Six Sigma.

### **Problem formulation**

What are the (3) most important root-causes of delays in the warehouse?

The problem has been further divided into three sub-questions:

- Which processes are bottlenecks?
- Which departments are affected the most?
- Is the current layout suitable for running a Lean warehouse?

## **1.3 Focus and demarcations**

The thesis will have a theoretical angle, and look at a specific warehouse in a specific company. As the thesis is written over the course of one semester, it will represent a snapshot of the current situation, and on-going trends may not be identified. It will emphasize current theory to provide recommendations and solutions to the challenges and issues identified.

Furthermore the thesis is limited in terms of looking at one part of the value stream. Lean utilizes a holistic approach for the entire organization, while the thesis will use the concepts and tools for a specific function in the organization. Although the surrounding functions are closely related and of great importance to include when implementing Lean, the focal point in the thesis will be on the warehouse. Accordingly, some challenges and improvement opportunities that could be identified when taking holistic approach may not be identified.



# Chapter 2

## Theory and methods

The following sections will explore the historical background and literature reviews of relevant topics — Lean, Six Sigma and warehousing. In addition the methods and techniques used to obtain and gather the relevant data for this thesis will be presented.

### 2.1 Case studies

Case studies are suitable when combining multiple methods of data collection, and the data can be both qualitative and quantitative. The end result can range from providing descriptions to testing and generating theories (Eisenhardt 1989).

Within logistics research, case studies are not a widespread research form as the focus has mainly been on quantitative data. However, a number of authors, e.g. Mangan, Lalwani, and Gardner (2004), Näslund (2002), and Ellram (1996), discuss the idea that qualitative research can contribute positively in logistics research. This thesis will take the form of an exploratory case study and focus on qualitative data to provide descriptions, while some quantitative data will be used for support.

While qualitative research has no standard approach, Näslund (2002) identifies four primary methods: *a)* observation, *b)* analyzing text and documents, *c)* interviews, and *d)* recording and transcribing.

These methods will be used for the qualitative analysis, albeit with a focus on observations and interviews. Some text documents and protocols will be analyzed to provide insight into how internal processes are and are supposed to be. The observations will be done both as scheduled "walk-alongs" and occasionally in a less structured and planned manner in order to observe normal, everyday situations. Some observations will also come in the form as questions and information learnt in highly unstructured manners, e.g. hallway conversa-

tions where short questions intended to clarify are asked, without any immediate follow-up questions.

Finally, a data-driven analysis will be carried out and form the basis for the quantitative aspects of this thesis.

### **2.1.1 Interviews**

Part of the data collection for this thesis will be done through interviews. The goal of the interviews is to gain insight, knowledge and a description of a phenomenon or problem. Moreover, interviews allows for personal opinions regarding current operations and procedures to shine through, which can be valuable in an exploratory case study.

The interviews will be structured with open questions and as individual interviews. These interviews are suitable when the goal is to gain a deep and detailed description of the phenomenon. It is further suitable when the interview relates to complex systems and large amounts of information. Finally they are suitable when it is difficult to define the end-game and the output of the interview.

Most of the interviews will be done with respondents, i.e. someone who has experience with the phenomenon. This has been determined suitable as the thesis will explore the unique and individual issues and challenges faced by the GE Dusavik warehouse, rather than taking a more theoretical approach and identifying generic issues and challenges in warehousing in general.

## **2.2 Lean**

The two terms *Lean* and *Lean Production* are relatively new and were first made popular in the book "The Machine That Changed the World",<sup>1</sup> as a result of an MIT study on automotive manufacturing. The philosophy behind it is not new, and is derived from the Toyota Production System (TPS).

### **2.2.1 Toyota Production System**

The Lean philosophy dates back to post-World War II Japan and the Toyota Production System. Eiji Toyoda, heir to the Toyota Co., visited Ford's Rouge plant in Detroit. After

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<sup>1</sup>James P. Womack, Daniel T. Jones, and Daniel Roos (1991). *Machine that Changed the World*. Harper Perennial, p. 323

introducing the Ford Model T in 1908, Henry Ford worked hard to increase the efficiency of his production lines. Inspired by the work of Frederick Taylor, author of *The Principles of Scientific Management*, Henry Ford made many innovative changes based on Taylor's ideas.

	<b>Craft</b>	<b>Mass Production</b>	<b>Lean Thinking</b>
<b>Focus</b>	Task	Product	Customer
<b>Operation</b>	Single items	Batch and queue	Synchronized flow and pull
<b>Overall aim</b>	Mastery of craft	Reduce cost and increase efficiency	Eliminate waste and add value
<b>Quality</b>	Integration (part of the craft)	Inspection (a second stage after production)	Inclusion (built in by design and methods)
<b>Business strategy</b>	Customization	Economies of scale and automation	Flexibility and adaptability
<b>Improvement</b>	Master-driven continuous improvement	Expert-driven periodic improvement	Worker-driven continuous improvement

Table 1: Comparison between craft production, mass production and Lean Thinking (Murman et al. 2012)

Henry Ford realized that the key to effective mass production was not with the assembly line. Ford was able to standardize parts and thus enable large production runs. In stark contrast to the competitors who relied on craftsmen customizing and fitting parts individually, Ford had standardized parts that were easily assembled and with less variation, in other words less customization was required during assembly. By reducing the actions required by each assembly worker Ford enabled a production line much more effective than that of their competitors. Furthermore, Ford also started having parts delivered instead of having the workers fetching the parts themselves. This, combined with few and simple actions in each process, helped reduce cycle time from hours to minutes between 1908 and 1913 (Dennis 2007). Henry Ford is most famous for inventing the moving assembly line, but his other innovations in mass production should not be overlooked. They have proven to be an important part of the foundation for the Toyota Production System and Lean.

Henry Ford successfully implemented mass production, and was able to significantly reduce the cycle time. Compared to competitors who were still using craft production techniques to produce their cars, Ford was able to greatly increase throughput. Even as production soared, Ford was able to cut the cost to the customer by two-thirds between 1908 and the

early 1920's (Womack, Jones, and Roos 1991; Dennis 2007).

A comparison between craft production, mass production and Lean Thinking is provided in Table 1, outlining the main differences between the three production techniques. Especially the overall aim differs greatly between the three techniques. Craft production aims to master the craft, and to provide a highly customized, high-quality product. Mass production, on the other hand, aims to increase efficiency through batch production. Throughput becomes the main focus, and quality moves from being an integrated part of the craft to becoming an inspection done afterwards.

### **2.2.2 Seven types of waste**

*Muda* is the Japanese word for waste, and is often described as any activity the customer is *not* willing to pay for. It is the activities that create no value to the customer, but still add cost. It would have no adverse effect on the end product if these activities stopped. Furthermore it is common to differentiate between non-value adding (NVA) activities and necessary non-value adding (NNVA) activities. This will be discussed in greater detail in Section 2.2.4.

In the Toyota Production System, Taiichi Ohno identified the following seven types of muda (adapted from Dennis 2007):

1. Overproduction
2. Waiting
3. Transport
4. Over-processing
5. Inventory
6. Motion
7. Defects

Lean is based on the assumption that by removing waste, business performance will be improved, quality will be improved, costs will be reduced and time will be better spent.

### 2.2.3 5S

The 5S system is a visual management system originating from Japan. The concept and system has its roots in the acronyms for five Japanese words;<sup>2</sup> *seiri* (sort), *seiton* (set in order), *seiso* (shine), *seiketsu* (standardize) and *shitsuke* (sustain). According to Dennis the 5S system is designed to create a "work environment that is self-explaining, self-ordering and self-improving." (Hubbard 1999; Dennis 2007; Kobayashi, Fisher, and Gapp 2008)

The vision is to be able to immediately detect abnormalities and waste, and that anything extra or unneeded in the workplace is removed. In the words of Chapman (2005); "[This means that] at a glance one should be able to see when things are out of order, if production has fallen behind or stalled, or if WIP is not where it should be." In other words, 5S should highlight and make waste *visible*.

Goldsby and Martichenko (2005) place a strong focus on the value of an organized workplace, and highlight the following five contributions of an organized workspace to Lean logistics:

1. Highlighting waste and clarifying the root cause of waste
2. Supporting standardized operations and orchestrating priorities
3. Reducing clutter and complexity that lead to quality issues in products and processes
4. Supporting measurement
5. Promoting safety in all operations

When the 5S system is implemented it strives to solve issues such as elongated lead times, low productivity, space constraints and late deliveries, to mention a few. One popular adverb is "a place for everything and everything is in its place", and this is at the heart of the 5S system.

The 5S system consists of the five pillars *sort*, *set in order*, *shine*, *standardize* and *sustain*. Use of the 5S system will for instance reduce walking and motion, reduce mistakes and make better utilization of space (Chapman 2005). All of the aforementioned wastes have to be removed in order to achieve a true Lean warehouse operation.

In the following the steps will be discussed in general, while a more specific analysis will be made in chapter 3.

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<sup>2</sup>The English translations are courtesy of Dennis (2007), and vary between authors. The translations of Dennis will be used throughout the thesis.

### **2.2.3.1 S1 — Sort**

The principle of visual order begins with the first step, *sorting*. The main goal of this is to remove anything that is not strictly necessary for day-to-day operations. This does not necessarily mean that it should be thrown in the garbage, but it should at least be moved to a suitable storage place. A popular proverb regarding this first principle of the 5S system is "If in doubt, throw it out".

One of the techniques that can be used when implementing the first pillar (S1) in the 5S system is red tagging. This is the key tool in S1, and consists of a tag containing the following (Dennis 2007; Hubbard 1999):

- Item classification
- Item ID and quantity
- Reason for red tagging
- Work section
- Date.

During the sort phase unneeded items are tagged with the aforementioned red tags by teams. Hubbard (1999) emphasizes that red tag teams should be cross-functional and include people from multiple areas of the organization. The reasoning behind this is that such teams will be able to be more critical of what to keep and what to tag.

When the tagging process is complete all the red tagged items are moved to a separate area. In this area all team members are allowed to look over the items and see if they actually need them in their respective areas. If a team member feels like the item is required, they have to plead a case for the item to stay. Furthermore it is worth noting that red tagging should be done regularly, for instance annually or quarterly.

The result of a successful S1 phase should be a workspace where all unnecessary items are removed.

### **2.2.3.2 S2 — Set in order**

When beginning the second pillar all the unnecessary items should have been removed. What is left are thus what is needed to carry out the daily operations. Step 2, *set in order*, is about organizing the tools and equipment in a logical and efficient manner. This aim is to reduce the time spent searching, remove unnecessary movement and remove difficulty-of-use waste. Step 2 includes creating two maps, one of the current state and one of an ideal

future state.<sup>3</sup> On the current state map the flow of materials and equipment is drawn out, and this should be done in a setting where feedback from fellow employees is encouraged. After analyzing how materials and equipment flow, create a new map and aim to reduce as much motion as possible. This could for instance mean to place commonly used items together.

A further part of the second pillar is organizing and marking the workplace. Dennis (2007) gives three keys to organizing: *what, where* and *how many?*

The ideal of this pillar is to have a system where anyone can find anything at any time, and where out-of-standard situations are obvious to anyone (Dennis 2007). Some of the tools and techniques is taping or painting fixed positions and areas on the floor. Doing this walkways and storage locations can be indicated. Likewise, shadow boards outlining what tools are supposed to go where follow the same guidelines.

### **2.2.3.3 S3 — Shine (and inspect)**

The third pillar is concerned with cleaning and inspecting the equipment used. By following a standard on cleaning and doing it regularly, equipment will last longer. Additionally, when cleaning one should also inspect at the same time, and thus faults with the equipment can be recognized sooner. Moreover, a clean workspace is more enjoyable than a dirty environment, giving a boost in morale.

### **2.2.3.4 S4 — Standardize**

Once the workplace is clean and organized, the fourth pillar can be implemented; standardize the work. This pillar is concerned with maintaining the good condition achieved by the three prior pillars, and prevent fall-backs.

Standardizing in the context of 5S is to a large extent making a playbook for S1 through S3. This standard should tell what is needed and not needed, what the color-coding from S2 means and where people can walk, and cleaning/inspection routines, to mention some of it. By creating a 5S scorecard and standard checking schedule this can become part of the daily routine. The standard operations created in this pillar should be the best way of working.

A standardized operation is one where the input requirements are known, the procedure is known and clearly defined, the time for each step of the procedure is known, and the expected output of the operation is known (Goldsby and Martichenko 2005).

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<sup>3</sup>See Value Stream Mapping in Section 2.2.4 for a similar process description.

<b>Inputs</b> What do I need to perform this task?	<b>Procedures</b> What steps do I perform to complete this task?
<b>Outputs</b> What are my expected outputs?	<b>Takt Time</b> How long should each step and each task take?

Table 2: Cube checklist for standardized procedures (Goldsby and Martichenko 2005, p. 132)

### 2.2.3.5 S5 — Sustain

The final pillar is making a habit of the 5S system and methodology. By involving all employees and providing training, 5S should become a part of the job and daily routines. As pointed out by e.g. Chapman (2005), Dennis (2007), and Kobayashi, Fisher, and Gapp (2008), 5S has to be seen and embraced as a holistic strategy — only then can business success or excellence be achieved. In other words, without involving all employees and committing to using 5S, i.e. only doing the first three steps (S1–S3), 5S does not achieve its full potential.

### 2.2.4 Value Stream Mapping (VSM)

Known in the Toyota Production System as "Material and Information Flow Mapping", it is often referred to as Value Stream Mapping (VSM) in modern literature. VSM is one of the key tools of the Lean philosophy and provides a powerful analysis of the *value stream*.

**Value Stream** All the actions (both value adding and non-value adding) currently required to bring a product through the production flow from raw material into the arms of the customer (Rother and Shook 1999).

**Value Stream** The series of steps to bring a product or service to the customer (Dennis 2007).

The power of VSM lies in its ability to visualize an entire operation, and see the flow beyond the single-process level. Value Stream Mapping has three categories for actions or activities;

1. value adding (VA) activities
2. non-value adding (NVA) activities
3. necessary non-value adding (NNVA) activities.



The first group of activities actually add value to the end product and are activities that the customer is willing to pay for. As an example, such an activity can be processing raw materials. Activities that fall within the second category are unnecessary and *muda*. There is no rational reason for these activities to be there, and they deliver no value to the customer, and should thus be eliminated. Some notable examples include waiting and unnecessary handling of items. The necessary non-value adding activities seem wasteful in the context that they do not add any value. Despite this, these activities are still necessary to perform. Some notable examples from Hines and Rich (1997) are walking long distances to pick up parts, unpacking deliveries, and transferring a tool from from one hand to another.

The VSM process starts by drawing a current-state map of how the situation is today. Based on this a future-state map is drawn, i.e. a map that shows the state one aim to be in. Using these two maps as the basis an implementation plan is created. The ultimate goal of VSM in a warehouse setting is to "optimize the flow of materials by redesigning warehouse activities such as picking and kitting, staging of goods, and how goods are actually packed, trucked, and sequenced for delivery." (Bartholomew 2008)

## 2.3 Six Sigma

Six Sigma is an improvement method aiming to maximize quality by identifying and eliminating sources of defects. Six Sigma originates from Motorola and was further developed by GE in the 1990s. The term "Sigma" originates from statistics, and measures how far a given distribution deviates from "perfection". The main idea is that thorough measuring and analyses will identify the root causes of defects, and help figure out how to eliminate them. A Six Sigma process is a process that does not produce more than 3,4 defects per million opportunities — a nearly flawless process (*GE internal resources*).

Six Sigma is considered to be a powerful improvement method, most of which can be attributed to the tools and techniques that Six Sigma consists of. Some of the most important tools include:

**Control Charts** monitor variance in a process over time and alerts to unexpected variance.

**Pareto Diagrams** identifies the problems that have the greatest potential for improvement.

Based on the Pareto principle, 20% of the sources cause 80% of the problems.

**Process Mapping:** illustrated description of how tasks are carried out and their relationship.

**Root Cause Analysis** aims to identify the cause of non-conformance in a process.

### 2.3.1 Define-Measure-Analyze-Improve-Control

Define-Measure-Analyze-Improve-Control (DMAIC) is a five-phase improvement cycle and a core principle of Six Sigma. A brief overview of the tools related to each phase is given in Table 3. DMAIC is used to assess and improve existing processes; to achieve a *Six Sigma process*.

**Define** Confirm the opportunity and define boundaries and goals of the project.

**Measure** Gather data to establish the "current state", what is actually going on in the workplace with the process as it works today.

**Analyze** Interpret the data to establish cause-and-effect relationships.

**Improve** Develop solutions targeted at the confirmed sources.

**Control** Implement procedures to make sure the improvements/gains can be sustained.

Process	Tools	
Define	SSPI Toolkit	Project ID Tools
	NPV/IRR/DCF Analysis	PIP Management Process
	Project Definition Form	
Measure	SSPI Toolkit	Process Mapping
	Value Analysis	Brainstorming
	Voting Techniques	Pareto Charts
	Affinity/ID	C&E/Fishbones
	FMEA	Check Sheets
	Run Charts	Control Charts
	Garge R&R	
Analyze	Opportunity Maps	$C_p$ and $C_{pk}$
	Multi-Vari	Box Plots
	Marginal Plots	Interaction Plots
	Regression	ANOVA
	C&E Matrices	FMEA
	Supply Chain Accelerator	Problem Definition Forms
	Time Trap Analysis	
Improve	Brainstorming	Pull Systems
	Setup Reduction	TPM
	Process Flow	Benchmarking
	Affinity/ID	DOE
	Hypothesis Testing	Process Mapping

Process	Tools	
	Gantt Charts Pert/CPM B's and C's/Force Field	Tree Diagrams PDPC/FMEA
Control	Check Sheets Histograms Control Charts Interactive Reviews	Run Charts Scatter Diagrams Pareto Charts Poka-Yoke

Table 3: DMAIC tools (Adapted from Table 2-1, George 2002)

For each of the five steps of DMAIC there are a number of available tools, as shown in Table 3. Some of the tools are developed specifically for DMAIC, while others are adopted from other manufacturing/improvement methods.

## 2.4 Lean and Six Sigma

Lean and Six Sigma can be combined in a business strategy. In the previous sections the goals and methods of Lean and Six Sigma are highlighted, in addition to the most important tools and methods. Lean Six Sigma is a term first coined by George in 2002, and it integrates the approaches from both the Lean and Six Sigma disciplines. As discussed, Lean aims to reduce waste, while Six Sigma aims to reduce variations in processes.

	Lean	Six Sigma
<b>Objective</b>	Deliver value to customer	Deliver value to customer
<b>Theory</b>	Reduce waste	Reduce variation
<b>Focus</b>	Flow focused	Problem focused
<b>Assumptions</b>	<ul style="list-style-type: none"> <li>Waste removal will improve business performance</li> <li>Many small improvements are better than system analysis</li> </ul>	<ul style="list-style-type: none"> <li>A problem exists</li> <li>Figures and numbers are valued</li> <li>System output improves if variation in all processes inputs is reduced</li> </ul>

Table 4: Comparison of Lean and Six Sigma (Murman et al. 2012)

Lean Six Sigma combines these two approaches into one unified path. In Table 4 Lean and Six Sigma are compared to highlight objectives, theory, focus and major assumptions.

## 2.5 Warehousing

In the following the theoretical background for warehouses and warehousing will be explored. Warehousing can be defined as the storage of stock prior to their use according to Coyle and Bardi (1980), where stock is divided into raw materials, finished goods and Work-In-Process (Muller 2011). The warehouse is a part of the "logistics branch" of the supply chain. This is further supported by the current definition by Council of Supply Chain Management Professionals (2013):

**Logistics Management** the part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements.

Lambert, Stock, and Ellram (1998) argues "warehousing has developed from a relatively minor facet of a firms logistics system to one of its most important functions."

For the past decades management philosophies such as Just-In-Time (JIT) and Lean production has increased significantly in popularity, and has given new opportunities for warehouse operations. IT tools, such as warehouse management systems (WMSs) have paved the way for improvements within warehouse operations. Improvements include real-time control of warehouse operation and stock levels and easier communication with the rest of the supply chain (Gu, Goetschalckx, and McGinnis 2007).

### 2.5.1 Warehouse objectives

The key objectives for warehouse operations are to<sup>4</sup>:

- Maximize the warehouse storage utilization
- Maximize the utilization of warehouse equipment
- Maximize the utilization of warehouse staff

In the following subsections warehouse functions and the theoretical foundation will be introduced.

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<sup>4</sup>See Mulcahy (1994) and Tostar and Karlsson (2013).

## 2.5.2 Lean Warehousing and inventory

Warehouses are a crucial part of supply chains, and their main role is to facilitate movement of goods through the supply chain. Even though new techniques such as Just-In-Time (JIT) aim to reduce inventory levels, inventory is in many cases still needed (Rushton, Croucher, and Baker 2010).

Holding inventory is defined as a waste in Section 2.2.2. At its core, holding inventory is a non-value adding activity and it might seem at first as though it should be eliminated. However, Lean and warehousing are not mutually exclusive, as pointed out by e.g. Garcia (2004) and Bartholomew (2008). They argue that the concepts of Lean are applicable also in logistics and warehousing. While the warehouse operations may remain the same for a Lean and a "non-Lean" warehouse, a warehouse utilizing concepts and principles from Lean will execute the processes in a different, and hopefully, more efficient way.

Lean and TPS are ultimately concerned with removing *unnecessary* waste, with emphasis on unnecessary. Reichhart and Holweg define three scenarios of the relationship between production lead time ( $P$ ) and delivery lead time ( $D$ ) the customer is willing to wait (Reichhart and Holweg 2007):

1.  $D = 0$
2.  $D > 0$  and  $P > D$
3.  $D > 0$  and  $P \leq D$

For these three scenarios the authors look at customers' willingness to wait compared to production and distribution time, as well as the characteristics of necessary inventory. Three industry examples are given for the scenarios, ranging from fast-moving consumer goods to one-off projects.

Fast-moving consumer goods (scenario 1), e.g. groceries, are characterized by customers who are not willing to wait for delivery — they require instant gratification. In other words, the acceptable delivery lead time  $D$  is equal to zero. Furthermore, the customers require this gratification at their location of choice; which makes the production lead time  $P$  almost irrelevant — customers know what they want, and they want it immediately. This thus requires a decentralized inventory system.

Scenario 2 applies to e.g. furniture, printers and automotive spares. Customers are willing to wait for these items, hence  $D > 0$ , however the production lead time is longer than they are willing to wait. In other words, they are willing to wait but not willing to wait long enough for Build-To-Order production. For these scenarios some inventory is required.

Finally scenario 3 applies to one-off projects, where the customers are willing to wait as

long or longer than the production lead time. Here no inventory is required in the distribution system.

The conclusion then, is that in some cases holding inventory is a necessity and it is not feasible to completely abolish the inventory. Rushton, Croucher, and Baker (2010), Muller (2011), and Coyle and Bardi (1980) point to some of the more important reasons for holding inventory. The following reasons are based on the condition that supply lead time (i.e.  $P$ ) is greater than demand lead time (i.e.  $D$ ).

**Predictability or smoothing** To smooth variations in supply and demand, inventory works as a buffer between what is needed and what is being processed. This buffer can prove valuable if, for instance, a rush-order is placed. Eases capacity planning and production scheduling. Demand variance is the root cause that has the greatest effect on inventory levels according to Davis (1993).

**Contingencies** Protection against e.g. strikes, vendor stock-outs, delays, natural disasters.

**Price protection** Can help avoid increased cost due to inflation, changes in the market or fluctuating exchange rates.

**Quantity discounts and lower ordering costs** By ordering large quantities it is often possible to achieve bulk discounts. Ordering costs will be lower when ordering in bulk. These are, however, double-edged swords — by ordering large quantities the holding costs will increase.

**Unreliability of supply** Holding inventory can hedge against unreliable suppliers. Even though unreliable suppliers ultimately should be replaced or rehabilitated, for a number of reasons it might be necessary to keep them as suppliers for the time being.

### 2.5.2.1 Inventory accuracy

Cycle counting is a warehouse auditing process designed to control inventory levels in a non-disruptive manner. Contrary to closing down the entire warehouse and doing a full physical inventory count, cycle counting is continually validating the accuracy of the inventory. It is done to a small number of items or stock keeping units (SKUs) every day in order to remain as non-disruptive as possible.

There are two approaches to cycle counting, random sample cycle counting and ABC cycle counting. The former is based on counting a random number of SKUs for each count. The number and which items to be counted are selected at random. Moreover, there are two techniques to this approach – *constant population counting*, where the same number of

items are counted each time. During this some SKUs might be counted multiple times, irregardless of value or usage stats. *Diminished population* is a technique where the counted SKUs are removed from the population and not counted again.

Group	Description	Pct. of SKUs	Pct. of COGS <sup>5</sup>
A	Critical	20%	80%
B	Significant	30%	15%
C	Other	50%	5%

Table 5: ABC/Pareto cycle counting

ABC cycle counting, or Pareto cycle counting, is the second approach to cycle counting. This method is based on the well-known Pareto principle, and divides SKUs into three groups — A, B and C. Items of high value and higher usage are counted more often, while items of lower value or low usage are counted more seldom. One variety of this approach is to group SKUs based on usage only, i.e. ignoring the value. Table 5 shows one example of grouping. It is worth noting that the percentage values here are not fixed, and should be adjusted and adapted for individual implementations. In relevant literature there are numerous tables like this with varying values.

### 2.5.3 Warehouse operations

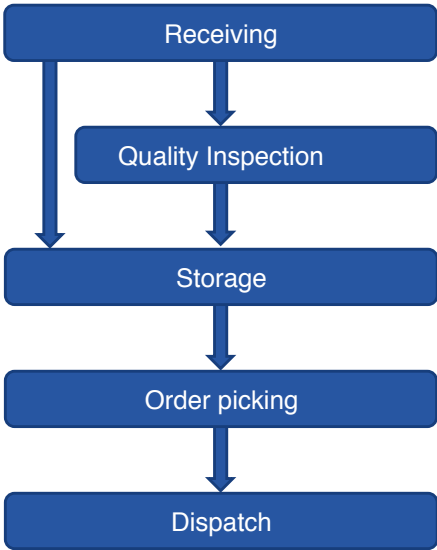


Figure 1: Warehouse functions

Warehousing can be divided into three basic functions: movement, storage and information transfer; following the definition by Lambert, Stock, and Ellram (1998). The authors further

<sup>5</sup>Cost of Goods Sold

divide *movement* into activities such as *a) receiving, b) transfer or put away, c) order picking and d) shipping.*

Warehouse functions are usually sequenced as shown in Figure 1 for inventory holding warehouses. There is a bypass added from *Receiving* to *Storage* that skips *Quality Inspection*. This is done in situations where the quality inspection phase is done by approved vendors before receiving. Another common bypass is also bypassing storage, which would lead to a cross-docking warehouse, which will be discussed briefly in Section 2.5.4.1.

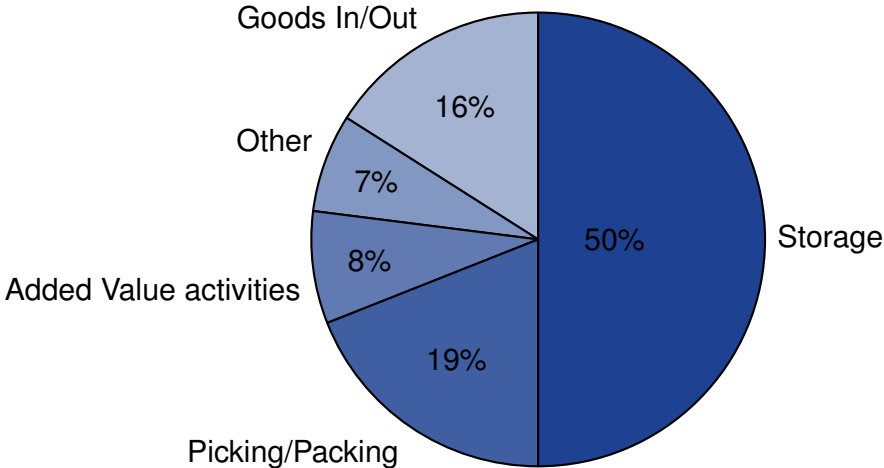


Figure 2: Warehouse floor usage (Rushton, Croucher, and Baker 2010)

Figure 2 shows floor usage generalized for a typical warehouse, and significant variations are to be expected for the wide variety of warehouses. Generally speaking, storage uses the most area, and a significant proportion is used to support the receiving and picking processes.

Rushton, Croucher, and Baker (2010) have once again generalized typical figures for conventional warehouses, found in Table 6. It shows the relative cost of each category, and as expected human resources account for a large proportion of the costs related to a warehouse. Furthermore, building related costs (building and building services) account for nearly the same percentage as staffing. In modern facilities with automated storage solutions, equipment will account for a significantly larger proportion while staffing can decrease somewhat. Staffing is still necessary for several of the aforementioned functions, e.g. receiving, quality inspection and dispatch, and IT related costs are also expected to increase with the introduction of automated storage solutions.

### 2.5.3.1 Receiving

Receiving is the first function and process in the warehouse when stock arrives. The SKU arrives from an external location, for instance a suppliers' factory. The receiving process



<b>Category</b>	<b>Percentage</b>
Staff	45-50%
Building	25%
Building services	15%
Equipment	10-15%
Information technology	5-10%

Table 6: Warehouse cost breakdown (Rushton, Croucher, and Baker 2010).

starts with unloading, followed by a checking activity, and then registering the incoming shipment in the warehouse management system (WMS). Receiving is the first process in the warehouse, and it creates the foundation for subsequent processes. Thus receiving is a very important process, as an error here can propagate throughout the system and the supply chain as a whole.

The receiving process includes checking the incoming goods. This activity is separate from the quality inspection (QI) process, which will be covered in the following. The checking activity consists of verifying the quantity and specifications of the incoming goods, for example controlling that the incoming shipment has a purchase order (PO) assigned to it, and that the part numbers match. Dependant on the supplier and the type of good being delivered, the checking activity can include verifying batch or serial numbers, verifying data sheets for chemicals etc. This activity works as a gatekeeper, ensuring that the items that are received and admitted into the warehouse adhere to the requirements.

Checking can be done in a number of ways depending on the type of good and the supplier. Some suppliers are known for delivering to specification and in the correct quantities, and all their deliveries are accepted based on the historical performance, also known as the *100% accept method*. On the other end of the spectrum is the *100% verification method*, where the entire delivery is checked. Somewhere in-between is the *random sample method*, where a fraction of the delivery is checked. If the checked fraction passes and fulfills the requirements, then the entire delivery is accepted.

At this point the stock becomes available in the Enterprise Resource Planning (ERP) system (GE uses a system named SAP) and the stock can be allocated to a project. Registering this information also creates the basis for monitoring e.g. supplier performance in terms of on-time-delivery.

Finally, receiving might include repackaging from one from e.g. a pallet to smaller cartons before moving the goods to storage.

One of the biggest challenges with receiving is scheduling deliveries. Often only statistical knowledge of arriving shipments is the only information available, meaning that the warehouse knows that delivery from a given supplier is supposed to be shipped/arrive on

a given date, and that is the only information. This makes work scheduling difficult, as the deliveries might be delayed or arrive before they are scheduled. Today information is made more available through technologies such as RFID scanning and advanced shipping notices. With this technology up-to-date information about when a delivery is incoming, in addition to more detailed information about quantities, weight etc. is made available to the warehouse. Combined with increasingly complex warehouse management systems that connect to suppliers' ERP systems, scheduling incoming deliveries can be done in a more efficient manner today compared to earlier, when the same, detailed information simply was not available (Gu, Goetschalckx, and McGinnis 2007).

### **2.5.3.2 Quality Inspection**

The quality inspection (QI) process ensures that the incoming goods fulfill quality requirements and are up to specification. As shown in Figure 1, it is a process that may be bypassed in some cases. Some incoming goods require strict quality inspection done in-house, others are done by third-parties and in some cases quality inspection is done by the supplier. Arguably QI can be seen as a part of the receiving process, if receiving is seen as all the activities from an incoming shipment comes through the entrance gate until it is put into storage.

To understand the value stream and flow in the warehouse, it is useful to distinguish between receiving and QI.

### **2.5.3.3 Storage**

Holding inventory is considered a waste in Lean production, and listed in Section 2.2.2 as one of the seven wastes. While it is theoretically possible to avoid holding inventory altogether with Just-In-Time deliveries, in many cases it is simply not feasible for an organization with manufacturing operations. Some of the reasons are briefly discussed in Section 2.5.2. The aim of the Toyota Production System and Lean production is to eliminate inventory by continuous, incremental improvement (*kaizen*). The goal then becomes to optimize which SKUs to keep in inventory, and how much of each. While this is an important and thoroughly researched topic, it is not directly relevant to warehouse management; it belongs in the field of inventory management. As such this topic will not be discussed further in this thesis.

The storage function is placed immediately downstream from the receiving/QI function, and is where the SKUs are moved into their storage location. While the process might seem fairly straight forward, it is a field where the decisions are many. One of the most important

decisions to make in this process is where to place the SKUs for storage. Locations and warehouse layout is researched and discussed by e.g. Dharmapriya and Kulatunga (2011), Gu, Goetschalckx, and McGinnis (2007), Bartholdi and Hackman (2014), and Berg and Zijm (1999), and in itself a large field which will be discussed in Section 2.5.4.

### 2.5.3.4 Order picking

Order picking is the process of retrieving goods in specified quantities from inventory and form a single shipment. It is a key warehouse function, and also one of the most resource intensive, requiring a fifth of the floor space in a warehouse as shown in Figure 2. Order picking is a costly activity and typically it accounts for 50% to 55% of the direct labor costs of a warehouse (Tompkins et al. 2003; Koster, Le-Duc, and Roodbergen 2007; Rushton, Croucher, and Baker 2010).

Order picking is a largely manual operation; the breakdown of how time is spent when picking is shown in Figure 3. As it can be seen, 50 percent of the time spent on order picking is spent on travel — a non-value adding (NVA) activity. It costs labor hours, but does not add any value to the customer, as mentioned in Section 2.2.2 as one of the seven types of waste.

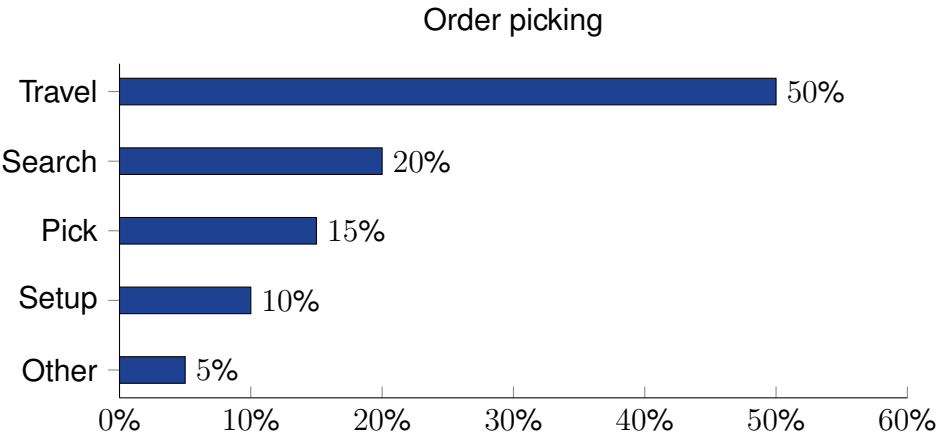


Figure 3: Order picking, time usage (Tompkins et al. 2003; Koster, Le-Duc, and Roodbergen 2007).

Moreover, a fifth of the time is spent on searching, which again is a NVA activity. These figures will naturally vary from warehouse to warehouse, and be subject to relatively large local variations. This is also evident in current research, where other authors operate with figures, e.g. 55% for travel and 15% for searching (Tompkins et al. 2003). In any case, travel is by far the activity that takes up most of the order-picking time.

As *manual* picking operations require significant time and floor space, the latter which could be utilized as additional storage, automatic storage and retrieval systems (often referred to

as AS/RS) are gaining popularity. Like virtually all other storage solutions they are available in a myriad of configurations and designs; some as horizontal lifts or vertical lifts designed for small items, while other systems are intricate systems designed to handle pallets weighing several tons.

Automated systems utilize floor space much better than single racks, at 48% and 36% respectively. Pallet-based storage with a single-deep rack design require an aisle between the racks that is wide enough to support a forklift or other equipment. This equipment is often used elsewhere and operated manually, requiring margins and enough space to work. On the other hand, an automatic system has a tailored machine used to store and retrieve. Due to the tailor-made nature, these systems can operate in a much smaller footprint and does not require the same margins. Narrower aisles allows for higher floor utilization, all else being equal, and since these systems are normally closed off to workers, they also promote and represent safer working conditions. Finally, automated systems are often taller, increasing pallet spaces per square meter (Rushton, Croucher, and Baker 2010).

While automated systems free up floor space and reduce the labor spent on order picking, they do represent a huge financial investment. Systems vary wildly in price depending on the specifications, but as a general rule automated pallet-based storage systems require a 24/7 operation to justify the investment.

#### **2.5.3.5 Dispatch**

In essence the dispatch process is the receiving process in reverse. The ordered SKUs are picked in the order picking process, and the dispatch process is concerned with verifying that the quantities are correct, that the items are in good order and are then shipped to an internal or external customer. Most challenges mentioned with regards to receiving are applicable in the dispatch process.

#### **2.5.4 Warehouse design and layout**

Modern and complex warehouses are tremendously difficult to design. In today's fast-paced and fast-changing markets, a warehouse must not only fully meet the requirement of today, but also be flexible and scalable to adapt to future growth and new requirements.

Warehouse design requires inputs on everything from location to size and calculated costs; product characteristics and throughput, inventory turn, service levels and order frequencies, to mention just a few.

While warehouse design is an umbrella term for all decisions related to the warehouse,

warehouse layout is a smaller field concerned with the internal design of the warehouse. The main goal is to reduce the amount of work associated with order picking. This can be achieved through a suitable and efficient design, balancing the trade-offs between speed, travel distances, space utilization, handling, access, safety, risk and cost (Berg and Zijm 1999; Richards 2014).

A suboptimal warehouse layout will drive costs on multiple areas;

- floor space is wasted,
- order picking takes more time than necessary, and
- operations are generally less efficient.

Improving warehouse productivity is given increasingly more attention, and research is mostly focused around improving order picking; the most labor/capital intensive operation in warehouses. It represents the highest cost of all the warehouse operations, and is thus often picked as the starting point for improvement processes.

In conclusion, an optimally designed warehouse ensures that throughput is maximized while minimizing resource usage, while keeping enough flexibility to adapt to new requirements.

#### **2.5.4.1 Cross-docking**

Cross-docking is a form of warehousing where the storage function is nearly eliminated. The incoming shipment goes through the receiving process (including QI where applicable), before being sorted and then onto outgoing transportation. In other words, the storage and order-picking processes are removed from the equation. Cross-docking is further illustrated in Figure 4.

The main issues in cross-docking are material handling and product flow. Especially for large operations the sheer number of SKUs in "transit" at the warehouse can be overwhelming, and the flow can be a determining factor for the success.

Cross-docking can be combined with more traditional forms of warehousing. In fact, many warehouses will run into situations where goods are immediately dispatched after completing the receiving process, and the theory of cross-docking can be applied.

Most of the costs in cross-docking operations are directly related to labor. Cross-docking is not much concerned with location and retrieval issues, as the product ideally flows right through without any need for storage (Bartholdi and Hackman 2014). Since cross-docking relies on moving incoming goods to outgoing transportation (*almost*) immediately, it does

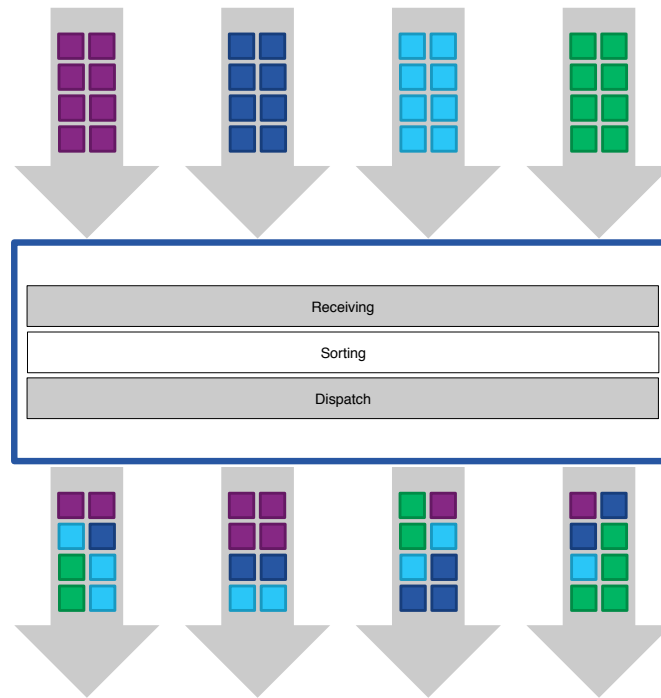


Figure 4: Cross-docking illustrated

require strong coordination and support from suppliers (Richards 2014) in order to facilitate this.

## 2.5.5 Warehouse performance

Like any organization should, warehouses should measure its performance compared to others, benchmarking and identifying areas in which to improve. Performance measurement is a tool to provide feedback to workers, and drive decision making and improvement processes (Andersen and Fagerhaug 2001). The performance of a warehouse can be given by multiple indicators, and they will be discussed in the following sections.

### 2.5.5.1 Performance Measurement

Performance measurement is a powerful tool that can be used as an early warning system. Financial statements are backwards-looking; they show what has happened, but not what is about to happen. Performance measurement, however, shows the day-to-day developments. Andersen and Fagerhaug (2001) compare it to the instrument panel and steering wheel on a car, i.e. the tools used to steer and monitor the current condition, while they compare financial statements to being the rear view mirror.

Furthermore, performance measurement can be used as a tool to implement strategies and policies, due to its behavior-altering ability. By using key performance indicators (KPIs) for the respective elements of a strategic plan and breaking them down into performance measures, these measures will normally stimulate the encouraged behaviour (Andersen and Fagerhaug 2001).

**2.5.5.2 Suggested KPIs**

Krauth et al. (2005) suggests a large list of performance indicators for logistics service provision. In terms of warehouse performance, the relevant indicators are listed below in Table 7.

<b>Effectiveness</b>		<b>Efficiency</b>	
Capacity utilization	↑	Total delivery costs	↓
Number of deliveries	↑	Cost per line shipped	↓
Perfect order fulfillment	↑	Pallets/m <sup>2</sup>	↑
Storage surface/volume/racks	↑		
On-time delivery performance	↑		

Table 7: Suggested KPIs (Krauth et al. 2005)

Other relevant KPIs can be related to safety (e.g. zero safety incidents or accidents, or near-misses) or the customers perspective (e.g. customer query time, service level, response time). In short, a myriad of performance indicators can be related to logistics and warehousing.<sup>6</sup>

A general performance measure is capacity utilization and capacity efficiency (Mangan, Lalwani, and Butcher 2008). They are given by:

$$\text{Capacity utilization} = \frac{\text{actual output}}{\text{design capacity}}$$

$$\text{Capacity efficiency} = \frac{\text{actual output}}{\text{effective capacity}}$$

*Capacity utilization* is based on the design capacity of the process. However, it is virtually impossible to achieve 100% utilization, i.e. reaching the design capacity. This is due to the likes of errors and delays, being unplanned or unavoidable in nature, but also due to e.g. maintenance and shift changes. The *capacity efficiency* on the other hand, accounts for this by using the effective capacity. The effective capacity is defined as the amount of un-

<sup>6</sup>The interested reader is referred to e.g Lambert, Stock, and Ellram (1998), Gunasekaran, Patel, and Tirtiroglu (2001), and Krauth et al. (2005) for further research on performance metrics for supply chains and warehousing.

avoidable occurrences subtracted from the design capacity. These performance measures are general in the context that they can be used to analyze virtually any process.

The first process in a warehouse is receiving, and metrics on receiving provide a valuable foundation for further analysis. Mangan, Lalwani, and Gardner (2004) suggests "receiving time" as a key metric, i.e. the time between a shipment arriving into the warehouse through to it being formally received into the warehouse management system (WMS).

With advanced ERP and WMS systems this is a metric of relative ease to measure. For example, in SAP, the specific ERP system used by GE, movements are registered with a three-digit "movement type" code, which represent goods being received, goods passing quality control and goods being available for project use/going into storage. When this data is entered correctly into the ERP system (i.e. being entered on a continuous basis and immediately after the movement has happened), this information is readily available for analysis.

Furthermore, Mangan, Lalwani, and Butcher (2008) argue that not only should receiving metrics be recorded, but also put-away metrics, e.g. number of units put away within in a stated time. This metric is aimed at identifying the relationship between products being received and products being put away, helping identify situations where product is sitting on the floor at the close of business.



# Chapter 3

## Analysis

Chapter 3 will present the findings from this case study, and describe the current state at the GE Dusavik warehouse. Findings from interviews and observations will be presented. The chapter begins by describing the physical warehouse, followed by the warehouse processes and finally an analysis of current Lean tools implemented. The chapter forms the basis for the discussion in Chapter 4.

### 3.1 Dusavik warehouse

The warehouse in Dusavik is located in the lower left-hand corner of the production yard, shown in Figure 5. The building itself combines the warehouse and offices, with the warehouse accounting for approximately half the ground floor footprint with ceilings stretching over two floors. The remainder of the building is used for offices, with some offices reserved for the warehouse while the remainder belong to another department. The workshops are clustered in the top of the production yard, while quality inspection and testing is positioned in a building in the lower right-hand corner of the production yard. Not included in Figure 5 are office buildings, located on what would be below the warehouse on the map. Finally a last production building is located outside of the main production yard, separated by a public road, located above and to the left of the workshops.

In addition to the storage space in the warehouse itself, two storage tents have been made available in the yard for additional storage. Moreover the yard itself is divided into multiple zones and used for storage of large, bulky items, e.g. metal bars/pipes and other equipment that can withstand being exposed to weather.

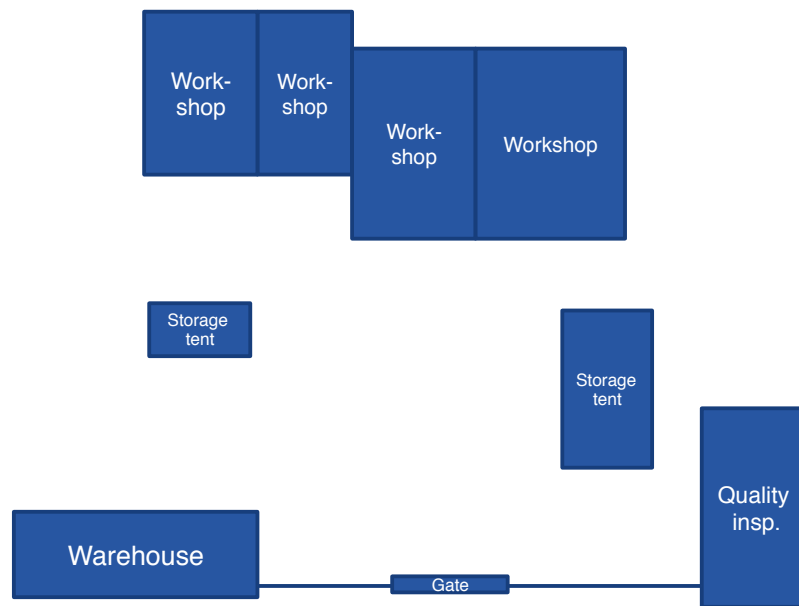


Figure 5: Yard layout

### 3.1.1 Warehouse layout

The warehouse itself organized with a U-flow design, meaning that the same area is used for receiving and dispatch. All deliveries are received through the same loading dock, which also functions as the exit point for dispatched items. Within the warehouse is also a small, walled-off office area with a few workstations, which are used by the members of the warehouse team whose roles and responsibilities include administrative tasks.

Inside the warehouse two storage systems are prevailing; single-deep racks for pallet-based storage, and vertical lifts for smaller items. Their individual usage and merits will be discussed in the coming. Finally, some of the storage is done simply by placing pallets and boxes of various sizes and shapes wherever free floor space can be found. The latter form of storage is mostly done for items that are in-between processes; waiting to complete the receiving process and being put away, waiting to be transported to quality inspection, waiting to be returned to a supplier or waiting to be delivered to a project.

### 3.1.2 Racks

The warehouse uses a system often referred to as adjustable pallet racking (APR). It is the most common form of racking, and is based on pallets being placed in single-deep racks. This means that each rack stores one pallet depth-wise, and two racks are placed back-to-back to create the aisles and aisle access. The racks utilize the full height of the warehouse and account for approximately 50% of the floor usage, including aisles.

Single-deep racking is a solution that gives relatively poor floor space usage as it requires aisles between every second rack, compared to denser systems. On the other hand, single-deep racking allows for direct access to all pallets, which is suitable when the number of SKUs is relatively low. This is one of the characteristics of the GE warehouse, where some pallets are exclusive to only one SKU, while others contain a small number of SKUs allocated to a single project.

### **3.1.3 Vertical lifts**

Vertical lifts and carousels are increasingly common in warehouses, and are used to efficiently store small items. They make good use of floor space by utilizing the height of the warehouse, allowing for more storage in a smaller floor footprint, and delivering a high-density storage solution. A computer controlled arm retrieves the requested shelf to a picking window placed at an ergonomic height. This allows for a large number of shelves with a relatively small floor footprint. Only the requested shelf is accessible, while the rest are tightly stacked inside the carousel or lift. GE has two vertical lifts for their small item storage needs. The particular models used are manufactured by Kardex Remstar and each has 77 shelves with tote bins.

The bins themselves are enumerated with a shelf and bin number. Furthermore, each bin is reserved for a single SKU, i.e. there is no mixing of materials in contrast to the pallet storage system. To retrieve a bin the operator uses a keyboard and an accompanying monitor is attached to the side of the Kardex, enters the bin number and the vertical lifts retrieves the correct shelf. The enumeration system is linked to SAP and the warehouse management system, ensuring that the shelves are easily accessible.

## **3.2 Warehouse processes**

Based on observations and data gathered from interviews, the processes the warehouse is concerned with will be analyzed in the following sections.

### **3.2.1 Receiving and dispatch**

The receiving and dispatch area is found near the warehouse entrance, and is centered around an L-shaped table, located in immediate proximity to the office and workstations. The table and workstations form what can be seen as the headquarters for the warehouse, seeing as all operations are coordinated from this area.

<b>Zone</b>	<b>Norwegian</b>	<b>Color</b>
Faults and defects	<i>Feil og mangler</i>	Red
Incoming goods	<i>Varer inn</i>	Yellow
To storage	<i>Til lager</i>	Green
Picking/packing	<i>Plukking/pakking</i>	Grey
Outgoing orders	<i>Varer ut</i>	Separate table

Table 8: Warehouse table zones

The table itself works as a temporary storage location while the incoming shipments is going through the receiving process. The table is color coded and divided into separate zones, given in Table 8, to separate incoming shipments from orders being prepared for dispatch. The color coding system is a prime example of how some concepts from 5S are being used in the warehouse. In Section 2.2.3.2 the merits of using color coding were briefly discussed. In this specific case, the warehouse uses color coding to define areas where goods are placed depending on their current position in the receiving or dispatch process. This is at the core of 5S and allows the warehouse team, in the words of Chapman (2005), "at a glance [be] able to see when things are out of order, if production has fallen behind or stalled, or if WIP is not where it should be."

In addition there is available floor space for temporary storage, also being used for these operations. The floor space is unmarked, i.e. there is no clearly defined part of the floor space that is directly reserved for a given function. This is in stark contrast to the aforementioned table, which is divided into zones using colored tape markings. The zones are summarized in Table 8.

To further be able to identify special cases of goods, there is a number of labels available. The labels are color-coded and consist of a large-font description (listed below), and in addition fields for e.g. project, delivery note or comments. Some of the labels are related to stock that is being allocated to a certain project, while others are designed to mark stock being blocked by ongoing processes elsewhere in the organization. Examples of these labels are "On hold (QI)", "Scrap", "On hold (bonded warehouse)", in addition to a few project-specific labels.

If and when the label is attached to incoming goods, the label will make that particular good visible as an abnormality that requires extra handling, extra attention or special allocation. This is yet another key point from 5S theory (see Section 2.2.3), namely that 5S aims to detect and identify abnormalities. It can thus be argued that at least some of the concepts from 5S has been implemented — while other concepts are seemingly outright ignored. It is also possible to claim that this can support standardized operations. By identifying what the inputs are (i.e. identifying a particular good as a special input for a special process), that can help achieving the first quadrant in Table 2 on page 10.

### 3.2.1.1 Receiving and SAP

Incoming shipments are received throughout the day at the warehouse. An employee at the entrance gate ensures that incoming transport carries goods to be delivered at GE, while the rest of the control procedures before accepting delivery are done by the warehouse team. Immediately after accepting delivery SAP should be updated with this new information to register that the shipment has arrived, but has yet to pass quality inspection (QI). This is represented by different goods received (GR) codes; 101, 103, 105, each representing a phase in the receiving process.

**101** Receipt for order

**103** Move to GR blocked stock

**105** Release from GR blocked stock

These codes are used through the ERP system and the WMS module. Every employee with access and any relation to incoming shipments, whether it be a warehouse team member, an employee in the sourcing department or a project planner or project manager, is given access to this information to allow them to better track and trace their orders.

After the delivery documents on the incoming shipment is controlled and checked against a PO, where it is verified that the goods being delivered actually belongs to the provided PO, the quantity and material numbers are controlled, and after passing this initial inspection/control phase, the shipment is recorded as "Received", with GR code 101. The next step in the process is the quality control, which as discussed in Section 2.5.3.1 can be done either by the warehouse team or by a dedicated QI team. When this step is initiated SAP is updated with GR code 103, at which point the material goes into stock — albeit blocked, as it has yet to pass quality inspection. And finally when the material has completed QI it becomes available stock, which is marked with GR code 105. When this happens the material is released as either freely available stock or available for a specific project, depending on what it was purchased as.

Currently the procedure is to update SAP with the order receipt (*GR 101*) as soon as it arrives and no later than 24 hours after arrival. While this is what the procedure calls for, it is not something that is strictly followed. It is widely known and understood within the warehouse team that the deadline is 24 hours after arrival, yet the deadline is not adhered to. The reasons are multifaceted; and one of the root causes pointed out during an interview with a warehouse employee is purchase orders. Within each PO is a large amount of information and requirements relating to the order. Material requirements and specifications are at the core of the purchase order, and these requirements and specifications in turn dictate QI procedures.

### 3.2.1.2 Receiving delays

One of the most common causes for delays in incoming shipments, apart from production delays and supplier-specific issues, is discrepancies between POs and the actual order, which commonly comes in the form of wrong requirements. This again boils down to the master data being erroneous, which spawns a situation where the ERP system has explicit requirements not fulfilled by the supplier.

The underlying reason for this can be traced to the discrepancy between two master data sets; one used by suppliers and sourcing, and the other used by SAP and the WMS. SAP uses a data set with information about customer-specific requirements for the materials and SKUs, e.g. if a serial or batch number is required, or if the delivery requires a Certificate of Conformity. If this requirement does not exist in the system used and accessed by suppliers and sourcing, however, the SKUs will be delivered without the required documentation and consequently the receiving process cannot be completed — in other words the SKUs will be blocked until further notice, and cannot be made available to projects.

The opposite is also at risk at happening, i.e. that SKUs are immediately made available. One prime example is machined parts, which have to go through quality inspection before being made available. If these are purchased and entered with unrestricted usage, meaning that they can be made available to projects as soon as they reach the warehouse, it is up to the warehouse to identify this discrepancy. The risk in this situation is that the machined part is placed directly in storage without passing the required quality inspection. Most of the time the warehouse team identifies it as a machined part based on their own knowledge.

For these situations the process of correcting and receiving delivery documents and certificates is tedious. The warehouse team realizes the incoming shipment lacks the required documentation when updating SAP, at which point the system will refuse to accept the goods receipt; and it will be stuck as *blocked stock*. The warehouse team then has to contact the purchaser responsible, who in turn has to reach out to the supplier and request the documentation. The information flow is then reversed.

Another largely contributing factor to incoming delays is corrections and reverse actions, commonly caused by errors in purchase orders. The clear impression is that there are few to no mechanisms in place to identify and correct errors when placing orders and creating POs, which causes delays further down the value stream — and it often becomes apparent when reaching the warehouse.

### 3.2.2 Inventory accuracy

The theoretical foundation of cycle counting is presented in Section 2.5.2.1. At GE the cycle counting is done through random sample counting, and diminishing population. This means that SKUs are removed from the "to be counted pile" after being counted, i.e. the population diminishes after each count. The vertical lifts (see Section 3.1.3) are counted on a daily basis, where one shelf is counted every day. This allows for the shelves to be counted over the course of a year, without requiring a facility shutdown. As previously mentioned, these shelves mostly contain small items, e.g. screws, connectors, nuts and bolts. Pareto counting is currently not done for any of the SKUs. Each of the two lifts contain 77 shelves, for a total of 154 shelves, corresponding to approximately two thirds of a work-year. The shelves themselves contain multiple tote bins, and every single bin is marked with a small sticker after being counted and verified. This sticker changes color on a yearly basis, and works as a small *poka-yoke*;<sup>1</sup> if the color corresponding to the current year is present, the count for that particular bin has been verified this year, and thus does not need to be counted again. A corporate requirement is that all inventory is counted at least once a year, and the diminishing population cycle count is able to satisfy this requirement.

During the count the counting team is equipped with a printed list from the ERP system containing the SKUs to be counted, their location and a field for entering the actual count. In addition to this the counting team is equipped with a printed list of the stock according to the warehouse management system. In other words, this means that the counting is not performed as a blind count. Blind counts are more time consuming, but prove better accuracy. The reasoning behind this is that with a "non-blind" count, the counters might be cheating by just confirming that the quantity *looks* right (Piasecki 2012).

"In order to ensure that accurate counting is maintained it is important that count sheets [...] do not give visibility of the system quantity to the counter."

As such, the main issue is that count is *supposed* to be performed as a blind count. While the instructions are seemingly clear, and the method is chosen by management, the counting team did the count as a "non-blind" during one observation. Upon asking about the counting procedures, this was explained as the way they were doing it, even though they knew it was incorrect.

### 3.2.3 Picking

The picking process is initiated when orders are received electronically from a project manager. Each order comes with a picking note generated by SAP, containing the SKUs and

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<sup>1</sup>Poka-yoke: mistake-proofing mechanism, originating from Lean Production (George et al. 2004).

quantity to be picked, in addition to their location. The warehouse operates a next-day deadline for order picking, where orders are to be picked within 24 hours. However, when creating the order and sending it to the warehouse it is not uncommon for project managers to request shorter deadlines.

SAP generates a picking note in conjunction with the WMS module, resulting in a picking sequence optimized by storage location — i.e. SKUs stored adjacently in bins or pallets are listed together. The pick route is one of the main ways to improve picking productivity. As noted, order picking often accounts for up to (or above) 50 percent of labor costs in a warehouse, and thus utilizing this resource effectively is one of the prime drivers of minimizing warehouse related costs. One of the key objectives for warehouse operations is to maximize the utilization of warehouse staff, and considering that order picking accounts for approximately half the labor further support the assertion that this is one of the main areas for improvement.

### **3.2.3.1 Picking and incorrect inventory levels**

Stock is allocated on a project basis, meaning that one SKU can be allocated to multiple projects; quantity x for project A, quantity y for project B and so on. For standard parts that are interchangeable (commonly screws, nuts, bolts), some might also be freely available, meaning that it is kept in GE's stock and not customer owned — and can be allocated to any project on demand.

Incorrect inventory levels are most commonly discovered when orders are received and the picking process starts. The cycle count is done with a yearly cycle, meaning it can take up to a full year before the same SKU is counted again. During this period of time the item can be handled multiple times, each representing a chance for some units to go missing.

Considering that stock is often customer owned and allocated to projects immediately after placing the order, it means in practice that the same SKU, with identical material numbers, specifications etc. can be placed in numerous locations in the warehouse. This allows for more efficiency in picking, when SKUs allocated to the same project are placed physically close to each other.

In the case where a current inventory level of a given SKU is incorrect, the process is outlined in Figure 6. It is a time consuming process that does not add any value. It begins with the picker requesting a complete list of all the locations of that particular SKU, as the first step of the process is to check every known location, aiming to identify and see if some of the missing SKU has been misplaced. In the case that the missing units are found, SAP is updated and the ordinary picking process continues as usual.

However, if the missing units cannot be found in any of the other known locations, the



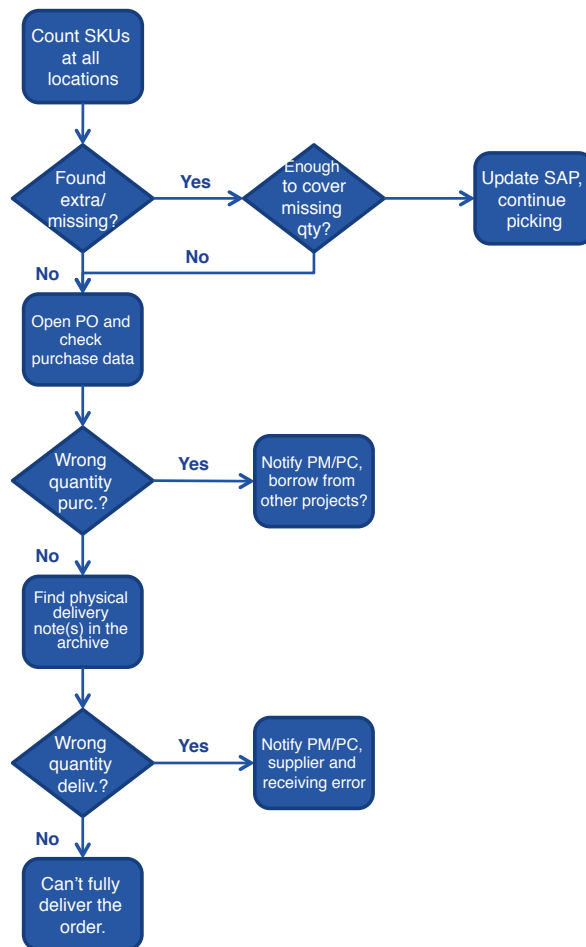


Figure 6: Picking process

PO is checked against the picking order. This step verifies that the actual quantity being picked was actually purchased. In the case that the wrong quantity has been purchased, the project manager/project coordinator<sup>2</sup> is notified of the discrepancy for follow-up.

If the correct quantity was indeed purchased and the PM/PC has no explanation of the discrepancy (e.g. borrowed by another project, known error in the PO, supplier issues) then the picker has to look through all the physical delivery notes. Delivery notes are attached to all incoming shipments by the supplier, and outline what the delivery contains; material numbers, quantities and other information for traceability. As a part of the receiving process<sup>3</sup> these documents are archived in a neighboring room to the warehouse. Delivery notes are organized by PO and physically stored in cartons. Considering that one purchase order can consist of multiple orders, and each order can be delivered in multiple shipments, it is prone to accumulate into a huge stack of paper, as seen in Figure 7.

The goal and end-game of this step is to verify that the ordered quantity was actually delivered. In the case that the supplier did not deliver the ordered quantity, this is the conclusion

<sup>2</sup>Abbreviated PM and PC in Figure 6, respectively.

<sup>3</sup>Not discussed in the prior.

of the investigation. In the case that the correct quantity was delivered, the process completes by concluding that the units have gone missing without further explanation. In both cases the PM/PC is notified for follow-up actions, e.g. granting permission to borrow from other projects or placing a new order for the missing units.

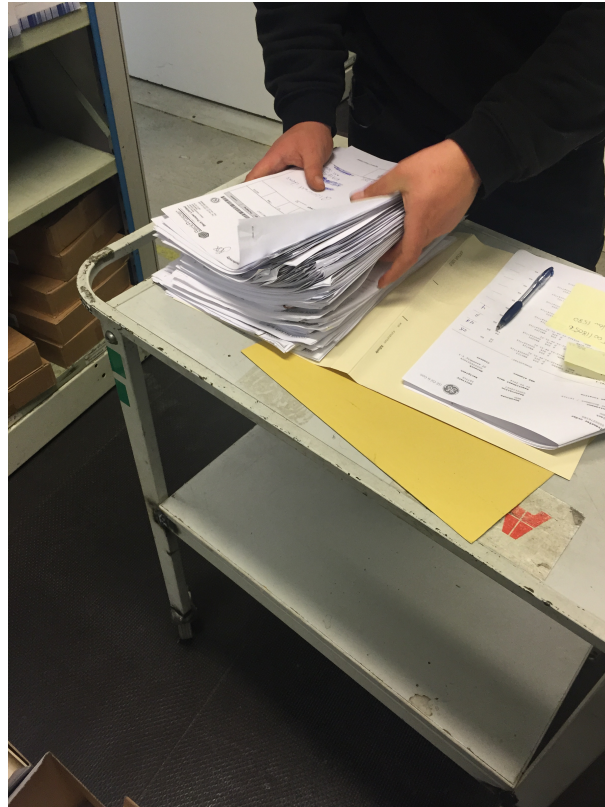


Figure 7: Warehouse delivery note stack

Besides, it is worth noting that this process is not a formalized process. During observations of this process it became evident that the sequence varied, or steps were done in parallel, depending on who were tasked with carrying out the investigation. Comparatively the sequence also seems to depend on whom of the warehouse staff with administrative responsibilities are on duty and available. The latter can be explained by the fact that access to SAP and the warehouse management system is limited to certain members of the warehouse team, thus their availability can be the decisive factor on how the process continues.

### **3.2.3.2 Value adding activities**

Normally the picking process consists of few to none additional value adding (VA) activities, nevertheless there are occasional orders where value adding activities are performed. Most of the notable examples of such VA activities are from standard, bulk goods, e.g. rope and wire. These goods can only be purchased in bulk, or rather it would be highly cost-inefficient

not to buy in bulk, and as such is stored in the warehouse and allocated as needed to projects. One value adding activity is to cut and provide the requested lengths of wire and rope. Apart from the above example, the warehouse generally does not deliver any additional VA activities as part of the picking process.

### **3.2.4 Planning work**

The GE warehouse is mainly concerned with scheduling and planning work originating from a) incoming shipments, which have to be received and stored, and b) orders, which have to be picked. In the particular case of the GE warehouse, this is source for basically all daily work. With increasingly more sophisticated ERP systems and warehouse management systems (WMSs) being able to communicate and exchange data with external systems, e.g. those of suppliers and logistics companies, there is normally good availability of information regarding incoming shipments.

WMS is a module within SAP, the ERP system GE uses throughout the organization. The WMS is a key tool to ensure that material handling is done correctly, and to keep track of freely available stock and project stock. When placing orders and creating purchase orders (POs), delivery date is one of the inputs, and a key piece of information for the remainder of the process.

SAP is currently not being used to its fullest capacity. It is implemented throughout the organization, and all departments have access to SAP, albeit not used exclusively or extensively. More importantly, not all work processes are adapted and adjusted to work in full conjunction with SAP. While not an issue in and of itself, as there often are more suitable tools and software specialized for specific work processes, it becomes a problem when this causes a loss of information that negatively affects other parts of the organization.

Two specific cases where such a loss happens will be discussed in Sections 3.2.4.1 and 3.2.4.2, which will identify how the warehouse is affected by two departments and their processes.

#### **3.2.4.1 Incoming shipments**

Every order from suppliers to GE is done through the local sourcing department, a cross-functional team responsible for sourcing for all projects at the Dusavik site.

Their process is fairly straight-forward for a typical purchase. A number of suppliers, the number depending upon the product being procured and other criteria, are contacted and a quote is requested. The suppliers then respond with their quotes, and a supplier is selected.

At this point a purchase order (PO) is issued; the formal initiation of the purchase. The PO contains information about the product/service being ordered, the quantity and price, plus more detailed information about the supplier, payment terms, delivery dates etc.

Synergistic effects first shine through when the PO is linked to a project, and information such as the delivery date is entered. Other valuable data, e.g. material data (bolt A324-2A01 weighs X grams, has dimensions LxWxH and is made of material Y, or chemical 102932-1 requires a special storage location) can also be linked to the PO. This allows SAP to know *what* and *how much* is arriving at or around a given date, and if there are any special requirements related to the delivery.

#### **3.2.4.2 Project orders**

Projects run at GE are structured using a work breakdown structure, whose structure is shown in Figure 8. The work breakdown structure allows for the project to be decomposed into work packages (WBS level 3), which again are granulated into activities. The activities are linked together in what is referred to as a network. A simplified example of a complete work breakdown structure is shown in Figure 8.

A well-structured work breakdown structure (WBS) includes all the work included in the project scope, and it further captures deliverables throughout the project. This characteristic holds true for all levels on the WBS, meaning that the entire WBS represents 100% of the work, and a single work package represents and contains 100% of the work required to complete the it.

On an activity level it is possible to assign required resources, most commonly required materials/parts, tools and required labor. This allows for even more synergistic effects within SAP, as the Project System is closely linked to Materials Management — the module that keeps track of all materials, including inventory. One of these effects occur when an activity is defined to require a given quantity of a given material. SAP has access to all material data and the current inventory, and thus can assist with ordering. When the required quantity is not available, SAP will create a Purchase Requisition for the sourcing department to act upon. SAP is then able to link activity-based material requirements to current stock and facilitate acquiring new stock.

As discussed and illustrated, SAP has the ability to connect departments in the organization with each other and allow for interdepartmental information flow. It links a purchase order to a supplier, can keep it up-to-date with new and relevant information, and this information is then available to use in other areas of the organization. With advanced systems like these it would be natural to assume that this allows the warehouse to have up-to-date information regarding the two aforementioned sources of work; *incoming shipments* and *project orders*.

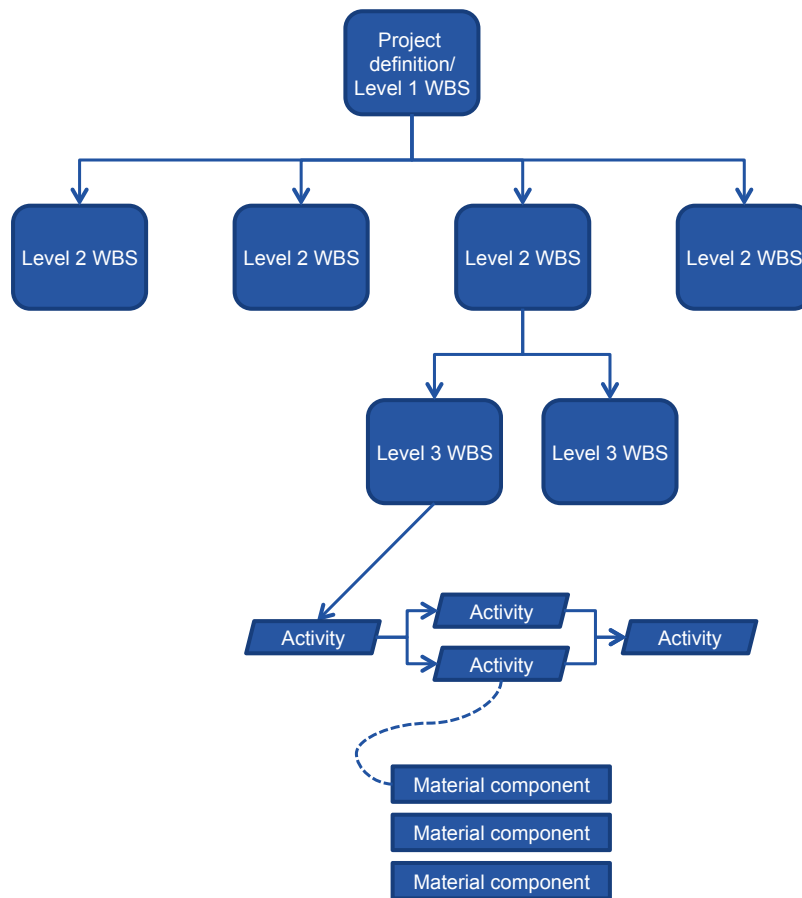


Figure 8: SAP Project System, WBS (Dowling 2007).

### 3.2.4.3 Planning for incoming shipments

Most POs are equipped with estimated delivery dates from suppliers. As any other form of data, it needs to be maintained and updated to bring any value to other departments. For the most time this is the case, and the PO is updated when there are changes to delivery dates. For some orders, however, the delivery date can be a "dummy date" if the actual delivery date is unknown when the order is placed. This is a situation that occasionally happens when a large number of individual orders are combined into one purchase order. In this particular case the delivery date does not represent a realistic or actual delivery date, although in most cases the supplied delivery date is a fairly accurate estimate of when shipments are supposed to arrive.

To summarize; delivery related information does exist, however it is not being used by the warehouse. The paradox here is that the warehouse team knows that they are constrained by not using the available information for planning and scheduling, yet they are not utilizing this information. The warehouse then operates completely blindfolded in terms of knowing

the number of and size of daily arrivals into the warehouse.

Seeing as the ERP system and WMS is not being fully utilized, the information the warehouse uses regarding arrivals is mostly limited to informal knowledge. This includes knowledge about the approximate frequency of arrivals based on historical data, and knowledge about the approximate size and weight of a typical arrival based on the supplier. Information of this type is certainly valuable and works as a guide on what to expect for an average day. It is, however, a poor tool to identify variation and capture and prepare for peak periods. These periods do happen, both on the receiving and order picking ends of the warehouse operations. Thus using the available information for better planning and scheduling will most definitely help the warehouse smooth and evenly distribute their workloads.

Another issue is that there are no systems to capture this informal knowledge; it is a purely experience-based knowledge retained by the warehouse team. In an extreme case where the warehouse team has to be built up from the ground it is more than likely that most of this information would be lost.

#### **3.2.4.4 Planning for project orders**

Projects are structured using a work breakdown structure, with the lowest level being called activities, as previously noted. To these activities materials and resources are allocated, providing an overview over the required tasks and the materials, tools and labor required to finish the tasks. In other words, all the work that goes into one project can be specified during the planning phase of the project and updated as the project progresses.

Currently the warehouse has little to no access to this information. The relevant modules in SAP are not being utilized fully throughout the organization; project planning is done on a high level in SAP, but the detailed information is kept in proprietary systems not accessible by SAP. The end result is that the warehouse does not know what to pick, or when to pick it, before the order actually arrives.

While there are some similarities to incoming shipments and the lack of information discussed above, availability of information is significantly poorer for project orders. On a given day the warehouse has little to no knowledge of the number of orders they will receive, and consequently no knowledge of the size of the incoming orders. Occasionally the picking notes will be released well in advance of the delivery date, at which point it becomes available in the list of orders to process. This is however the exception rather than the rule.

This inevitably makes planning extremely difficult, and as a result the warehouse is occasionally inundated with a backlog of orders. When capacity is exceeded it then becomes an issue of prioritizing orders. Currently there are no formal criteria for which orders are given priority over other orders. It can best be described as it was by one of the interviewees;

"whoever shouts the loudest gets his/hers order first."

This statement is the product of simplification and exaggeration, perhaps a bit tongue-in-cheek, albeit one that helps substantiate the current situation — that there is no formal, documented nor clearly communicated priority system when the capacity in the warehouse is exceeded. The prevailing principle the daily operations are based on, is trying to fulfill most orders, without being specific on how to achieve this.

Most orders are submitted through official channels, i.e. through SAP, which allows the warehouse to perform *some* prioritization during periods where the capacity is exceeded. The next-day deadline is also well known throughout the organization, nevertheless it does not prevent employees from the workshops to approach the warehouse directly. It is not uncommon that the workshops sends employees down with a small post-it note with an order, and that they are requesting it even before the actual order and picking note is created in SAP.

Occasionally projects will place an order far in advance, with a specific delivery date. Due to reasons beyond the control of the warehouse (e.g. space constraints, items not delivered yet, chemicals with storage restrictions), these orders cannot be fulfilled in advance, but rather have to wait until the predetermined delivery date. According to one of the interviewees, it does happen these orders are *not* prioritized in peak periods, resulting in the order not being fulfilled within the deadline after all.

Consequently, in peak periods when the capacity is exceeded, it becomes an environment where prioritization is based on *informal knowledge, pressure and random selection*.

Operations become overshadowed by fire fighting, with the warehouse team working to ensure that most orders are partly delivered. By delivering only the most important parts of the order, the underlying idea is that this will prevent projects from completely stopping due to shortage of parts. However, "*the most important part(s)*" is a loosely — if at all — defined term, and the warehouse team has no information about the ongoing work in the workshops and current needs. Consequently, they are limited to the information given to them by the workshop or the project manager with no way to verify the actual necessity of the ordered parts, and they have to rely on trust and hope that no parties try to gain an advantage at the expense of others.

### **3.2.5 Paperwork**

Attached and related to all incoming orders are POs and delivery notes. Upon receiving an incoming shipment, the relevant paperwork is printed and organized in different shelves, depending on which warehouse process the shipment is currently undergoing. There are

shelves for incoming shipments that are not yet checked, outgoing shipments and shipments moving to storage, in addition to shelves for incoming and outgoing shipments to QI.

When an incoming shipment arrives, the delivery note is signed and together with the PO placed in a shelf aptly named "*PO, not checked*". This marks the start of the receiving process, and as the shipment progresses through receiving and makes it way to the other processes, the papers are moved correspondingly.

<b>Shelf name</b>	<b>Description</b>
PO not checked	Items that are delivered, but not yet checked against the PO
PO out	Items to be returned to the supplier or other third-parties
PO storage	Items ready to be moved into storage
QI delivery	Items to be delivered to quality inspection <sup>4</sup>
QI pickup	Items to be picked up from quality inspection
SAP receiving	Items that are checked against the PO, but not yet entered into SAP

Table 9: Paperwork and work dispatch system

In addition to function as a tracking system, it also functions a work dispatch system. Each stack of paper represents a piece of work needed to be done. It further gives a visual clue to the amount of work remaining. For instance, the employee in charge of entering incoming shipments into SAP will pick up a stack of paper from the "*SAP receiving*" shelf, process it according to the description in Table 9 and then physically move the paper stack to the "*PO storage*" shelf. This action confirms that the preceding step is complete, and that it is ready for the subsequent step.

When a stack of paper is moved from one shelf to another it is simply placed on top of what is already in the shelf, making it seem at first as though it is a Last-In-First-Out (LIFO) process. During interviews, however, it became evident that work occasionally is prioritized after the LIFO principle, occasionally it is picked at random, or in cases where a specific delivery has been requested to be prioritized through the warehouse, it will be picked based on knowledge.

In summary, the work dispatch system, in conformity with the rest of the warehouse processes, can be characterized as following an arbitrary procedure.

<sup>4</sup>As previously mentioned, QI is located in a neighboring building. See Figure 5.



### 3.2.6 Quality Inspection

QI is mostly done by a separate department, and the incoming goods are sent back and forth between the warehouse and the QI building for the quality inspection. A surprising issue came up during one of the interviews; returned goods that *did not* pass the inspections are not scheduled to be returned to the supplier or otherwise handled. These goods are assigned to a special stock category in SAP named "blocked stock", which is used for any form of stock that did not pass quality inspection or lacks documentation.<sup>5</sup>

According to one of the interviewees from the warehouse, it does happen that these returned goods that were supposed to be used for projects are stuck in the warehouse waiting for return transport to be scheduled, which occasionally is significantly delayed. The result is reduced storage capacity for the warehouse.

## 3.3 5S in the warehouse

The purpose of 5S is to create and maintain organized, clean, safe and high-performance workplaces. 5S is a system consisting of the five pillars; sort, set in order, shine, standardize and sustain (George et al. 2004).

There are evidence of some concepts from 5S being included in the warehouse. The most obvious example is in the receiving and dispatch area (see Section 3.2.1), the entrance to the warehouse where all incoming shipments pass through here. This area is centered around a table which is used for smaller items. The table itself is divided into multiple zones, as was shown in Table 8, with separate zones for the individual processes such as receiving, dispatch, storage, in addition to a separate zone for items with faults or defects.

The warehouse gives off an impression of being untidy. The floor is filled with pallets and other large, bulky items, some of it used for permanent storage, while other parts of the floor are used as temporary storage. These incoming shipments are usually placed directly on the floor in the cartons they arrive in, without any further planning given to their placement at the time being.

The analysis will granulate the 5S system to the five pillars and analyze these individually, outlining the current state, before analyzing it as a whole.

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<sup>5</sup>This is not to be confused with "GR blocked stock", which is an intermediate step in the receiving process.

### **3.3.1 S1 — Sort**

The goal of the first pillar of the 5S system is to remove all items from the workplace that are not needed for the current tasks.<sup>6</sup> It is worth noting that this step is not simply rearranging things neatly, it is an actual cleaning, and only the essentials should be left.

Examples of such unnecessary items is paperwork, manuals, defective items, broken tools, old cleaning supplies and outdated posters, signs and memos. All of the aforementioned items are present in the warehouse in its current state.

Some notable, more positive examples are present. The receiving process utilizes tags to identify special items (see Section 3.2.1), which can be seen as a form of "opposite red tagging". The tags indicate that the items are being worked on and will be processed in due time.

### **3.3.2 S2 — Set in order**

Pillar number two aims to arrange the needed items in the area and to identify/label them so that anyone can find them or put them away.

The warehouse has relatively few specialty tools available at their disposal, and the most commonly used tool is a knife. The knives are carried in pockets, and thus not relevant for this section. However, there are some speciality tools used for value adding activities (see Section 3.2.3.2), and these tools can be found around the warehouse, with no fixed "home address".

One positive implementation of a concept from S2 is marking walkways and storage locations with paint on the floor, indicating where it is safe to walk and areas designated for storage. This is done for walkways through the warehouse, and the same is done for quarantined stock. The same has been done in the aforementioned receiving and dispatch area. While the markings exist, they are in many cases not respected, with items being stored in areas that are not designated for storage, resulting in e.g. obstructed walkways or inaccessible storage.

### **3.3.3 S3 — Shine**

Shining/cleanliness is not evident in the warehouse. Naturally, in environments where the same forklifts are used inside and outside, where large crates are moved about, and dirty

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<sup>6</sup>Goals for S1 through S5 all use their respective definitions from George et al. (2004).

SKUs are returned from workshops, some dirt is to be expected. Without further dwelling on this issue, there is room for improvement.

### 3.3.4 S4 and S5 — Standardize and Sustain

For the last two pillars of the 5S system, Standardize (S4) and Sustain (S5), no analysis will be carried out. The reasoning behind this is that even though some tools and concepts from 5S are currently being utilized in the warehouse, it is not done in a 5S context. Considering that 5S is a systematic approach to achieving a visual workspace, many of the tools and concepts are expected to be found in applications, albeit not necessarily through the same systematic approach. The last two pillars are concerned with standardizing the work, maintaining the system that has been implemented and making it into a habit. As such, to analyze and discuss this without the prior pillars in place, would only make moot points.

## 3.4 Data analysis

The data collected from SAP is from a report of blocked stock, i.e. any form of stock that did not pass quality inspection.<sup>7</sup> This report was generated and saved on a daily basis to capture changes over time, rather than a snapshot of a given day. The capture period was from early February 2015 to late May 2015.

The report itself contains detailed information about each of the units placed in blocked stock, including the Goods received (GR) date, which project it belongs to and a material description. Especially the GR date is of interest, as this represents the date when it was first placed in blocked stock.

The data sets used in this thesis includes both stock previously, but not currently blocked, referred to as *released stock*, and stock currently blocked, referred to as *blocked today*. The former category is the most interesting, as this shows stock that has been blocked and has now been released, giving insight into how long it usually stays blocked. The latter category is not equally interesting, as some of the currently blocked stock has been blocked for several years, indicating that these outliers are forgotten or otherwise ignored stock still registered in the data source. Furthermore, with no model for predicting how long currently blocked stock will stay blocked, this data is best left excluded from the analysis.

Figure 9 shows the data (n=194) grouped by intervals of 10 days, and the number of occurrences within each interval. As can be seen from the supporting data in Table 10, the

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<sup>7</sup>See Section 3.2.6.

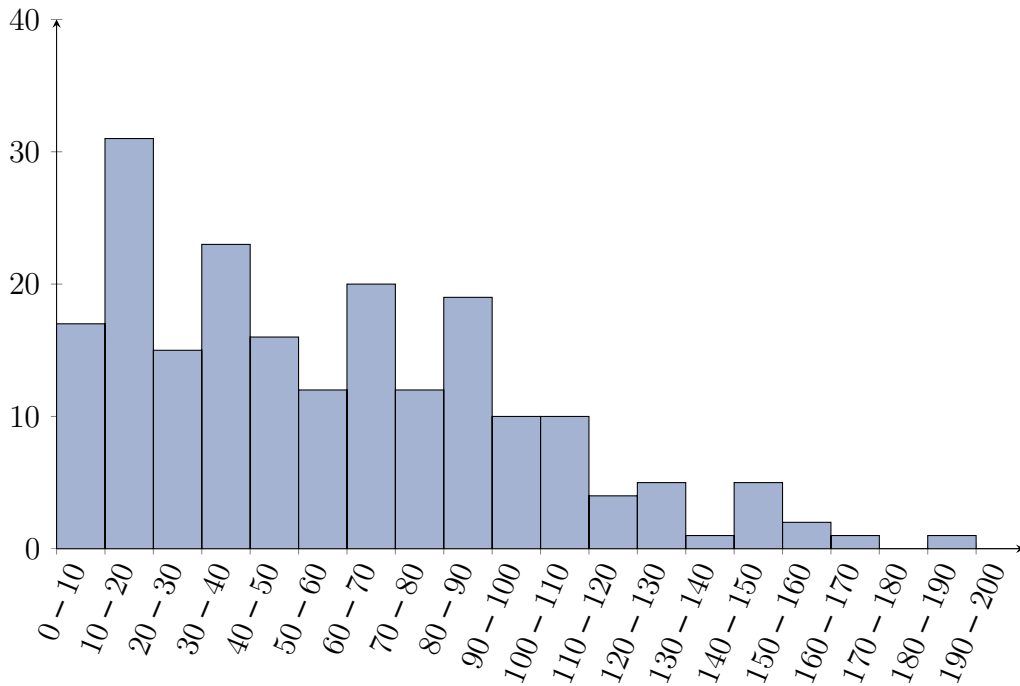


Figure 9: Frequency intervals, released stock

mean number of days is approximately two months. However, the standard deviation of the population is significant.

<b>Released stock (days)</b>	
<b>Mean</b>	59,6
<b>St.dev.</b>	55,1
<b>n</b>	194
<b>Max</b>	525
<b>Min</b>	2

Table 10: Supporting data for Figure 10.

Attempts at discovering and identifying patterns within the blocked stock was not successful. During the analysis a pattern between the type of stock, project or department, and the number of days blocked, was unsuccessfully searched for. After accounting for the relative size of departments and projects, no patterns were found in the data.

# Chapter 4

## Discussion

The problem at hand and what this thesis set out to answer was "*What are the (3) most important root-causes of delays in the warehouse?*", and these root-causes will be identified and discussed in the following.

This thesis will not be able to identify and propose specific solutions to all issues discovered during the case study. One of the core concepts of Lean is continuous improvement in small, incremental steps. Thus, any recommendations presented will be presented under the assumption that it will be continuously improved, and that they are not seen as the final solution — merely somewhere to start.

What will be presented are the issues identified to have the most impact and be most important to change, combined with recommendations of a general character. The recommendations will be based on the theoretical framework in the thesis framework, and connect current theory to practical applications.

### 4.1 Planning

One of the largest challenges faced by the warehouse is planning and scheduling work. In the analysis two separate cases where loss of information caused negative effects were outlined, and they will be discussed jointly in the following.

**Root-cause 1: Poor planning and scheduling of work**

Running a warehouse, trying to achieve the key objectives of maximizing storage utilization, equipment and staff, all while maintaining the responsiveness required by customers, is complex and filled with trade-offs. Doing so with little information about the scope and amount of work is even more challenging, bordering on impossible.

One of the single largest issues, and one of the root-causes of delays in the warehouse has been identified to be the lack of detailed planning and scheduling. The receiving and order order picking processes are resource intensive; the latter often accounting for more than half the labor costs in a warehouse. Both these processes require use of equipment, such as pallet trucks and forklifts, in addition to human labor. Achieving maximum utilization of the warehouse equipment and staff without a detailed plan of the work day is an unmanageable challenge. More importantly, without planning it is virtually impossible to prepare for and smooth peak periods. It is during these peaks that the capacity is exceeded, and delays occur.

From a Lean perspective there are seven types of *muda*, identified in the theoretical foundation,<sup>1</sup> and receiving and order picking are both processes prone to experience what Lean defines as waste. Especially the wastes of waiting and transport are commonly observed in these processes, and in a Lean warehouse the overall aim is to eliminate waste and ensure efficient flow of goods. Thus this root-cause of delays is not only interesting to analyze and discuss from the perspective of reducing delays, but also from a theoretical Lean warehousing perspective.

Within the receiving process room for improvement is found especially with planning and scheduling work. While it theoretically would be ideal to have access to all relevant information, the current situation is that the available information is underutilized. As such, increasing the amount of available information without using it will bring no value.

Access to more information requires collaboration between departments within GE and with suppliers and third-parties such as logistics providers. One specific tool to improve collaboration and allow for short-term planning, is facilitating for suppliers and logistics providers to send *Advanced Shipping Notices*. Such notifications inform of a pending delivery, and may also contain information about the items in the shipment, physical dimensions and other related information.

The positive effects of facilitating for more detailed planning of work are many. Most importantly, it would give the warehouse knowledge in advance when to expect peak periods, instead of the current state where the peaks come as surprises. Furthermore, it will allow for a smoother flow where some tasks can be scheduled to periods where there are no orders, allowing the tasks to be finished without interruption. With knowledge of pending deliveries through *Advanced Shipping Notices*, deliveries that require the use of special equipment can be scheduled to arrive when the warehouse has capacity.

When the warehouse is not able to meet the receiving deadline, the backlog causes a ripple effect throughout the organization. This is especially evident for rush orders; which risk being placed and forgotten for a period of time, with no indication of it being a priority

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<sup>1</sup>See wastes in Section 2.2.2.

shipment due to a long backlog.

The same benefits and positive effects are also achievable when improving the order picking process. While the warehouse has slightly more information availability regarding planned orders, with some orders being notified of in advance and booked in SAP, for the most part the warehouse has no knowledge of future orders.

As orders are received, the warehouse operates with the aforementioned 24 hour planned lead time or deadline. During peak periods it is not realistic to process orders within the deadline, and thus delays occur. On the other hand, during non-peak periods orders are processed before the deadline. Without any procedures and systems in place to allow for planning on a basis of more than 24 hours, it is difficult to see that order picking will cause fewer delays in the future. Thus, planning and scheduling must be facilitated for order picking to cope with the delays.

For both receiving and picking, the key is access to relevant information. Sporadically the warehouse receives information in advance of upcoming orders, but this is the exception rather than the rule. If orders were to be placed in advance, it would allow the warehouse to use tools such as *kanban boards* to prioritize work.

#### **4.1.1 Kanban boards**

As discussed above, more information regarding incoming shipments in the receiving process and project orders in the order picking process will inevitably help the warehouse better plan their workdays. One tool that can be used to achieve this is *kanban boards*.

A kanban is a visual tool used to achieve JIT production, and is at its core an authorization to produce or withdraw parts or finished goods (Dennis 2007). Kanban boards are used to visualize workflows and visualize and limit Work-In-Process (WIP). A kanban board will utilize many of the concepts and ideas found in 5S, namely to see when things are out of order, the current state of operations and if WIP is not where it should be. Further, it combines these concepts with core concepts from Lean and JIT production, e.g. leveling work<sup>2</sup> and reducing wastes such as waiting, transport and motion. The result is a powerful tool to visually plan and track work, which allows for immediate identification of unusual or unwanted situations, e.g. too much WIP, long backlogs or upcoming peak periods.

The current tool for planning work on a daily, the paper stacks and shelves discussed in Section 3.2.5, lacks one very important aspect that a kanban board could address — allowing for prioritization, which will be discussed in the context of receiving and order picking in the following chapter.

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<sup>2</sup>*Heijunka*, Japanese for production leveling and a core concept in Lean.

A full-fledged, ready-made Kanban board does not exist. There is no final solution with a fixed template that works for every organization, it is rather a tool that requires customization and continuous improvement for each individual organization. As such, the recommendation cannot be more specific than recommending to begin the process of developing a Kanban board.

### 4.1.2 Value Stream Mapping

Value Stream Mapping is another key tool recommended to use in the context of increasing planning and scheduling. VSM maps the current processes, identifying information flow and material flow across departments and outside the organization, including suppliers and customers.

Through creating a map of the current processes, VSM aims to identify and increase visibility of bottlenecks and NVA activities that can be eliminated in the current-state map. From the future-state map an implementation plan is created. VSM spawns understanding of current and future processes, which is key in any improvement process.

VSM is specifically recommended for its ability to detail both internal processes and how it affects customers and suppliers.

## 4.2 Receiving and order picking

Planning and prioritization are closely linked, and prioritization can be seen as a continuation of the former. As pointed out in the analysis and discussed in the above, the warehouse has little information about upcoming orders.<sup>3</sup> This lack of information and lack of opportunities for planning, combined with workshop employees, i.e. the customers, directly approaching and requesting orders, leads to peak periods where the warehouse has no chance of delivering all orders on time. It further leads to tasks being re-prioritized.

**Root-cause 2: Lack of prioritization in peak periods**

During peak periods there are no standardized procedures or formal criteria for prioritizing orders, and this is one of the root-causes of delays in the warehouse. Peak periods are in this case considered to be periods where the order picking demand exceeds the capacity, i.e. a period where delays will occur.

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<sup>3</sup>See Section 3.2.4.4.



Considering how difficult, if not borderline impossible, it is to avoid these peaks without better planning and scheduling of work, the focus for this discussion will be how to effectively prioritize during peaks.

During peaks the warehouse has knowledge of the current orders; that is orders to be picked within 24 hours. In addition to these orders are the ad-hoc orders from workshop employees showing up at the warehouse. What the warehouse has no knowledge of, however, is the relative importance of the elements in each particular order. Orders often contain parts required by the workshops not only immediately, but also for the next few days or even weeks. In other words, the orders received are not used in conjunction with JIT production or one-piece/continuous flow. The reality is that the workshop stockpile parts and SKUs from the warehouse before actual use.

This leads to what is the first aspect of order picking to improve; the ability to split orders into multiple orders. Large orders containing items that are not immediately necessary being processed during peak periods inevitably leads to longer delays, and thus by allowing the orders to be split into a prioritized part and a non-priority part, some of the pressure during peaks could be removed.

The current procedure for splitting orders is through verbal and informal communication channels. The warehouse has does not have knowledge, formal nor informal, of specific materials and parts needed for ongoing projects in the workshops, and thus rely on project coordinators to prioritize these lists. By creating a standardized and more formal procedure for splitting orders, the process of prioritizing the lists would be more streamlined and faster — yet again easing the pressure during the peak periods in the warehouse.

Continuous improvement, *kaizen*, is at the core of Lean. The proposed improvement should only mark the start of the improvement process, not a final solution. According to Lean theory, the overall goal should be to permanently reduce batch sizes and converge on one-piece flow.

## 4.3 Inventory

The third and final root-cause of delays in the warehouse will be divided into several key points and areas, all under the umbrella of incorrect inventory levels.

**Root-cause 3: Incorrect inventory levels**

While it might seem as an obvious statement that delays are caused by trying to deliver something that does not exist, there is more to it than so. It is a significant root-cause with

connections to a number of processes and operations within and outside the warehouse. The key points will be structured to follow the same sequence as the warehouse functions.<sup>4</sup>

### 4.3.1 Receiving delays

The first item under the incorrect inventory levels umbrella can be attributed to receiving delays. There are two main reasons to delays in the receiving process; *a)* poor work scheduling, and *b)* master data discrepancies.

The former has already been discussed earlier in this chapter, while the latter is the reason that falls under this umbrella, and has yet to be discussed. It was analyzed in Section 3.2.1.2, where the point of discrepancies in master data sets was first made.

When incoming shipments lack required documentation, they cannot be accepted as available stock, and will be placed in *blocked stock* until the documentation is received. When placing the order this was obviously not intended nor planned for with regards to the delivery date. Thus, the NVA activity of correcting this can be time-critical, and if not done in due time, will cause a delay when the stock cannot be released and used.

Further looking at this, several wastes are identifiable; waiting, over-processing and defects being the most obvious. In some cases the waste of transport can also be attributed to this, if blocked stock is physically moved to a separate location, as it could following the visual management concepts from 5S, and correspondingly has to be moved back again.

These master data discrepancies can cause significant delays, as shown in the data analysis in Section 3.4 and the corresponding figures and tables. With mean time in blocked stock nearing two months and another peak around the three month mark, it is obvious that these discrepancies can cause huge delays. While not all blocked stock can be attributed to master data discrepancies; in fact much of it is due to failed quality inspection, this data does illustrate and quantify some of the effects of the discrepancies and the process that follows.

When operating with master data sets with errors and discrepancies between them, the solution is obvious: to clean up the data, standardize procedures and ensure that the data is maintained and inspected, and finally making it a habit and stabilizing. In other words, the concept and goals of 5S applies here.

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<sup>4</sup>See Figure 1 and Section 2.5.3.

### 4.3.2 Receiving and SAP

The full receiving process, including any QI done by the warehouse, is supposed to happen within 24 hours. All incoming shipments are further expected and supposed to be registered with a goods receipt the same day as the shipment arrives.<sup>5</sup> Especially this second deadline is important to adhere to, as this will allow anyone waiting on a shipment to see that it has been physically received and is in-house, though has yet to complete the receiving process.

As a result, when this deadline is not adhered to, neither the warehouse nor the project planners or other related parties waiting on a given shipment knows where it is. Consequently, it is even more challenging to prioritize this shipment if needed, and the registered inventory level does not reflect the physical/actual inventory.

### 4.3.3 Missing inventory

Chapter 3 outlined the picking process and the process when incorrect inventory levels are discovered.<sup>6</sup> The latter is of interest for the root-cause currently discussed, as it helps explain the tedious process.

The process has been fully outlined in the analysis, and it is a time-consuming process that certainly merits its own improvement project. The workflow presented in the analysis is not a standardized procedure, nor one that is followed strictly — it depends on who is performing it, and further on who is available. Considering that missing inventory during the picking process can propagate quickly to downstream processes, this is a challenge and a process that deserves a stronger focus and a standardized process that is adhered to.

### 4.3.4 Cycle counting

Inventory inaccuracy can be further reduced through inventory counting, and the method chosen by GE is cycle counting.<sup>7</sup> One factor greatly contributing to *more* accuracy is performing counts as blind counts, i.e. not giving visibility of the supposed quantity to the counter. This is however the exact opposite of the current procedure, where the warehouse team operates with two sheets simultaneously; the sheet on which they note the actual count and a sheet showing the supposed/system quantities. A new, standardized procedure and stricter guidelines would help cope with this issue.

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<sup>5</sup>GR 101 as discussed in Section 3.2.1.1.

<sup>6</sup>See Section 3.2.3.1.

<sup>7</sup>Described in Section 3.2.2.

## 4.4 5S

The 5S tool is a powerful tool in Lean and commonly applied in a wide variety of organizations. Its strengths come from employee driven implementation and creating a platform for standardization.

The three root-causes outlined and discussed in this chapter all share a common ground; *low visibility*. Whether it be root-cause 1, where it is low visibility of upcoming work, or root-cause 2 where it is low visibility of prioritized work, or root-cause 3 where it is low visibility of inventory levels; one common ground is exactly that — low visibility.

Unfortunately this does not entail that 5S is the *one* tool to solve the issues. What it does entail, however, is that 5S can and should be one of the tools used to solve some of the issues, and used in conjunction with the aforementioned tools and recommendations. Furthermore, as 5S is an inclusive tool employing all employees as contributors, it gives the added benefit of empowering employees to make their own decisions and recommendations, which is at the heart of Lean; *worker-driven continuous improvement*.

5S will have an effect on all root-causes discussed, and also at other issues and challenges identified in the analysis, and will be briefly discussed in the following subsections.

### 4.4.1 5S implementation

A 5S implementation should follow the steps outlined in the below to achieve the goals in Section 2.2.3.

**Sort** According to the first pillar of 5S, *sort*, all unnecessary items should be removed. In the context of the warehouse, this means sorting through and identifying any unnecessary stock. The preferred method of achieving this is through red tagging. Any items red tagged, i.e. items that are identified as unnecessary and queued for a review process, should be placed in a separate location for review. Using the storage tents for this temporary storage will remove them physically from the main warehouse, thus allowing for increased visibility of current stock levels.

Using a cross-functional team is highly recommended for red tagging. A red tagging team should include representatives from the warehouse, workshops and project planners, to ensure a critical look at the entire warehouse.

**Straighten** The second pillar should organize everything in a logical and efficient manner. In a warehouse, one of the more efficient manners of organizing and storing items is through single-deep racking, which is currently the main form of storage at GE. In this

step the relative positions of the pallets in the racking system should be analyzed and potentially organized in zones to further increase efficiency.

Furthermore, items placed outside of fixed storage systems, e.g. in the yard or placed in the storage tents, thought and care should be given to positions and accessibility of other items, ensuring that the items to be picked first are not placed behind items for long-term storage.

**Shine** To shine in a warehouse context does not only include tidying and cleaning, but also clearly marking labelling, locations and specific zones so that they are immediately visible to anyone.

**Standardize** Standardizing work processes and procedures is a point made in previous sections of this thesis. As the warehouse has reduced inventory levels and cleared out any unnecessary items, procedures should be updated to reflect and maintain this. It should be clear to anyone what inputs are required, what steps are to be performed and what the outputs are. By standardizing procedures, measurement through e.g. DMAIC tools can be facilitated, which provides the statistical basis for reducing variation.

**Sustain** One of the keys to sustaining the new and improved operations within the warehouse is by including employees. 5S is a suitable tool as it includes and involves from the bottom-up in the organization, which is at the heart of Lean.

This does include involving all employees, and it relies on the employees understanding the concept of 5S and how it can improve their workspace and daily work. This will require training, education and inclusion of all employees.

#### **4.4.2 5S for lack of planning and scheduling of work**

The first root-cause, *lack of planning and scheduling of work*, can be helped by 5S especially for daily planning and scheduling. In the prior the merits and value of using a Kanban board for planning was discussed. A Kanban board shares many of the same traits as 5S, and these two tools work well in conjunction. Thus, implementing 5S and cleaning the workspace; allowing to physically see the status of current tasks, will help the Kanban board work efficiently. These two tools in conjunction will give immediate visibility to what the current backlog is, what the current WIP is, and what has been completed — and thus the current and future needs of labor and other resources.

### 4.4.3 5S for lack of prioritization in peak periods

The second root-cause can be helped by 5S through increased visibility. When prioritization is necessary, a clean workspace where the current status of any given job can be visually seen, has the potential of increasing the flow of goods. The prioritized items and tasks will be immediately visible, in contrast to the current-state where it is hard to see which items belong in which process.

### 4.4.4 5S for incorrect inventory levels

Finally, 5S and a clean workspace will give visibility to current inventory levels through removing unnecessary items (*S1*). This process alone will likely result in identifying excess stock for some items, and missing stock for other items. Furthermore, what can be described as "forgotten stock" can be identified through the red tagging process and will be removed. Through this 5S is a tool to increase visibility of incorrect inventory levels.

## 4.5 Lean Warehouse

A Lean warehouse is a warehouse utilizing concepts and principles from Lean to decrease and eliminate waste. As such, there is no single factor that decides if a warehouse is Lean or not. The sub-question from the problem formulation; "*Is the current layout suitable for running a Lean warehouse?*", will be discussed in this section.

At the core of Lean is eliminating waste, and thus one way of analyzing and discussing how Lean a warehouse is, is looking at to which extent it facilitates elimination of the 7 wastes, or rather which wastes are present and naturally occur with the current layout and setup.

**Overproduction** Considering that the warehouse does not produce any goods, the waste of overproduction is not applicable. However, one of the *effects* of overproduction is increased warehouse costs, as items that are not sold are produced and need storage. In a broader scope, a Lean warehouse should not receive any excess items from productions, albeit this is a factor outside the realm of warehousing.

**Waiting** The waste of waiting is present in the warehouse, e.g. waiting for feedback when inventory is missing, waiting to use handling equipment (trolleys, forklifts etc.) or waiting for the vertical lifts to retrieve parts.

All these aforementioned sources of waste are present in the current-state. However, most of the time there is sufficient access and availability of handling equipment.

While the vertical lifts are more efficient than the manual alternative, it does come at the cost of waiting. Waiting for feedback will be further related in over-processing.

**Transport** The waste of transportation is a necessary waste. The warehouse layout has the entrance and exit gates in close proximity of the receiving and dispatch areas, reducing the distance incoming and outgoing items need to travel, reducing waste. Furthermore, since the warehouse is compact and large, bulky items, or rarely used items, are stored directly in the yard or in storage tents, the amount of travel within the warehouse for the receiving and order picking processes is reduced. Thus, the warehouse eliminates unnecessary transport to a large degree.

**Over-processing** Over-processing is a waste that does happen in the warehouse, and in particular there is one process where it is especially visible. When inventory levels are incorrect, the process outlined in Section 3.2.3.1 is filled with over-processing waste, in addition to the waste of waiting. While this is a waste that is caused by a process, rather than the layout, arguably a warehouse implementing 5S and increasing the visibility of inventory levels will help avoid this scenario, and thus avoid the process. With this perspective, the warehouse layout does spawn the waste of over-processing.

**Inventory** Inventory is by definition a waste, albeit in some cases a necessary waste.<sup>8</sup> Thus, waste of inventory will be any unnecessary inventory, and there is no basis for claiming that the layout of the warehouse spawns any unnecessary inventory. While there are unnecessary items in inventory, these are the result of processes. The argument regarding 5S as in over-processing applies here, and thus some waste of inventory can be attributed to the layout.

**Motion** The warehouse handles a wide variety of SKUs varying greatly in size, shape and weight. As such, many of the SKUs will entail unnecessary motion. However, physical equipment such as the vertical lifts are ergonomically designed, with the picking board in a ergonomically correct height, reducing the waste of motion. In sum then, the warehouse layout has some aspects that facilitate elimination of motion, and some that do not.

**Defects** Considering that the warehouse does not produce any items, defects on the account of the layout were not identified. The defects that may happen in the warehouse are commonly due to physical handling, e.g. dropped items, cutting incorrect lengths.

In conclusion, the warehouse layout is for the most part suitable for running a Lean warehouse. The design and layout sufficiently reduces transport and waiting, and while some aspects of the warehouse, especially physical visibility, contributes to the waste of over-processing and inventory, most of the wastes can be attributed to the warehouse processes

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<sup>8</sup>See Section 2.5.2.

rather than the warehouse layout.

## 4.6 Affected departments

The main focus of this thesis has been on the root-causes of delays, the processes related to the root-causes and bottleneck processes. The sub-question "*which departments are affected the most*" remains unanswered until this point, although it has been hinted in the previous sections.

The warehouse is the entry point for all deliveries and goods delivered to GE for use on projects and for keeping inventory. As such, any delays in the warehouse will first and foremost affect the departments downstream from the warehouse. Following the analysis, the downstream departments are identified to be the workshops and quality inspection. These two departments are directly downstream from the warehouse, where delays will propagate directly. Effects of these delays are outlined in prior sections.

Additionally, departments such as sourcing are affected by delays. The sourcing department and the purchasers do receive some of the blame for delays, even for the part of the ordering process that is out of their hands, i.e. receiving at the warehouse.

## 4.7 Data analysis

The goal of the data gathering was to support the claim that discrepancies in master data sets is one of the root-causes of delays. This has not been successful, and the expected patterns were not found.

What can be seen in the data represented in Figure 9 is a collection of SKUs organized by intervals on how long they were blocked before being released. The data was gathered over a period of approximately 17 weeks, from early February 2015 to late May 2015, on a daily basis, allowing to see developments and gather detailed data on current blocked stock levels.

However, while no trends or patterns were found in this data, it does identify a significant amount of stock tied up in blocked stock. Blocked stock is not chargeable to customers until released, and the monetary value of the stock carried by GE can be significant.

As a general recommendation and in alignment with the goals of Six Sigma, the new processes recommended in this thesis should be measured. The goal of Six Sigma is to improve processes through measuring and analyzing. While the data analyzed provided no



trends nor patterns, it did identify and quantify the problem of blocked stock. This should be further used in new analyses, following the DMAIC cycle, to continuously measure and analyze data. Over a longer time span and with expert teams analyzing more data than this thesis had, patterns and improvement opportunities might be found.

Benchmarking and comparing KPIs, for instance those suggested in Section 2.5.5, can further support performance measurement in the warehouse and identify areas of improvement. By comparing and benchmarking against best-in-class warehouses, the effects of the suggested improvements can be measured.

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# Chapter 5

## Conclusion

The thesis set out to explore the concept of Lean warehousing and identifying challenges and issues related to this concept. Moreover, the thesis aspired to provide and recommendations on tools to achieve a Lean warehouse and cope with the challenges identified in the case study of a warehouse in Stavanger. The problem formulation chosen was:

What are the (3) most important root-causes of delays in the warehouse?

Through observations, discussions and interviews, the root-causes are determined to be 1) poor planning and scheduling of work, 2) lack of prioritization in peak periods and 3) incorrect inventory levels. The root-causes are linked to current processes in the warehouse and interrelated departments, and found to be connected to both processes within the scope of control of the warehouse, and outside.

The first root-cause relates to communication and information sharing between departments and with suppliers and third-parties, in addition to internal processes within the warehouse. Similarly, the second root-cause calls for standardization of procedures, and clear communication between departments. Lastly, the third root-cause encompasses internal processes, inter-departmental communication, and warehouse procedures.

Recommendations for these three root-causes can be characterized by the need for standardization, whether it be of communication lines, procedures or data entry. Through standardization it will not only be possible to ensure a smoother flow and work leveling, but also eliminate arbitrary judgement. Further, they share a common recommendation in implementing 5S; a tool introduced in the theoretical framework, analyzed in the analysis and discussed in the discussion.

Furthermore, three sub-questions were sought to answer;

1. Which processes are bottlenecks?
2. Which departments are affected the most?

### 3. Is the current layout suitable for running a Lean warehouse?

Bottleneck processes were found to be the receiving and order picking processes. These two processes are the most prone to cause delays further in the value stream, and thus should be key areas of improvement. They are the most time-consuming processes, and they represent the start and the end of warehouse operations; defining the outer boundaries of the warehouse operations. The two processes are further the most time critical processes where there is little slack.

The departments affected are identified to be the downstream departments, although some effects can be traced to upstream departments as well. Finally the layout and its suitability to run a Lean warehouse is found to be satisfactory, and the discussion concludes that it is processes rather than the layout preventing it from being a Lean warehouse.

It is well known throughout the organization that the warehouse has issues with delays. The underlying reasons, however, are not well known; it seems that there is little understanding that it is not entirely a result of the warehouse itself, but rather a combination of both the warehouse and the connected departments. Throughout the analysis and discussion, core tools from Lean and Six Sigma such as process mapping and Root Cause Analysis are used to identify and discuss the challenges faced by the warehouse. Furthermore, systems and techniques are recommended to give the warehouse a strong set of tools to improve their processes and consequently reduce delays. The tools proposed and recommended are designed to facilitate measurement, to be used in conjunction with Six Sigma tools to measure and analyze variations in processes.

To finalize the conclusion a point will be remade, as it is of the out-most importance. The root-causes and challenges identified, similar to the recommendations, are merely a starting point; to achieve a true Lean operation improvements should be done on a continuous basis with worker involvement throughout the whole organization. New challenges will arise, new improvement opportunities will become visible, and the future-state becomes the current-state; and the cycle continues.

## **5.1 Limitations and further research**

Throughout this thesis several subjects are found to be of interest for further research, although hindered by the relevance to this thesis.

Benchmarking to measure performance could provide helpful insight to how the warehouse performs against best-in-class warehouses. By benchmarking directly against other similar warehouses, where downstream production is a combination of maintenance and one-off projects, would be an interesting topic for further research.

Furthermore, a Lean application requires the involvement of workers and employees. It would thus be an interesting area of research to explore the willingness and enthusiasm for the employees to implement Lean throughout the organization. In combination with a follow-up study measuring the effects of the recommendations proposed, could explore and track changes in delays and link these changes to the effects of implementing Lean and Lean tools.

Finally, Lean has to happen to the whole organization to unleash its full effectiveness. This thesis is limited in the sense that it analyzes and looks at Lean in the context of a single department. This is also the starting point for further research; a holistic approach analyzing and looking at the whole organization would be a truly interesting research topic bound to identify further improvement opportunities.

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# Appendix A

## Interview guide

Most interaction with warehouse personnel was through casual observations and non-interrupting questions during the workday. The interviews were done at a later stage and are thus more specific, and done with warehouse personnel. Interviews with other employees from other functions were planned, but turned out unnecessary as questions were answered through ad-hoc meetings.

The follow-up-questions were in some cases asked, in others not. They were defined as questions to keep the interview going.

- How do you plan on a daily basis?  
*Follow-up: How do you plan on a weekly basis?*
- When doing inventory counts, what does the process look like and how are the items to be counted chosen?
- What is the timeframe from a delivery is made until it is registered in SAP [the ERP system]?  
*Follow-up: Any backlogs?*
- Which errors do you experience in SAP?  
*Follow-up/clarification: Which errors are from your side, and which errors are made by others?*
- Are there any limitations in SAP that makes your job harder?  
*Follow-up/clarification: Both in terms of entering data, pulling data and planning work.*
- Are there any specific instructions/procedures for the receiving process for given suppliers?
- Do you use any functions in SAP and the WMS to dynamically choose storage positions?

- What are the timeframes you adhere to for receiving and orders?
- Does it happen that other employees do the receiving process on your behalf, either with or without authorization?
- Does it happen that other employees self-service from the warehouse, the yard or the storage tents?

The interviews were adjusted accordingly as they progressed, and always ended with the open-ended question "Do you feel I have left out something you would like to discuss?"