Improving Materials Supply Processes to Assembly Lines Through Toyota Production System and Lean Manufacturing

- a Case Study at TePe Munhygienprodukter AB

A Master's Thesis

By

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Abstract

Improving Materials Supply Processes to Assembly Lines Through Toyota Production System and Lean Manufacturing – a Case Study at TePe Munhygienprodukter AB

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Purpose – TePe Munhygienprodukter AB (TePe) is moving the production facility designated their toothbrushes as part of their expansion phase. Not only do they face challenges due to a two-floor production, but also do they face efficiency and safety challenges in their materials flow. The purpose of this paper is, therefore, to construct recommendations on improving TePe's materials supply processes to assembly lines through Toyota production system (TPS) and Lean manufacturing (Lean).

Design/methodology/approach – A constructive research approach is conducted to develop problem-solving constructs for TePe in regards to abovementioned challenges. In addition, a dual case study is conducted to find gaps between TePe's actual and potential performance. A comprehensive theoretical framework of TPS/Lean bridges case-specific practice and theory.

Findings – This research has found seven constructs for TePe to mitigate many of the challenges they face, and improve their overall flow efficiency through TPS/Lean, namely: setup time and batch size reductions, layout changes, and an implementation of a supermarket, a Kanban system, a 5S initiative and managerial principles (i.e. Genchi genbutsu, Visual management, Kaizen, 5 Whys and a re-evaluation of strategies). The company can save 0.74 MSEK yearly in inventory holding costs through a setup time and batch size reduction with 57 and 50 per cent, respectively. The constructs provide a clean, structured replenishment system, eliminating the problematic safety hazards altogether. There is also a chain of indirect benefits from all seven constructs. Therefore, management is vital for building and fostering a new culture of continuous improvements and employee engagement.

Originality/value – This paper contributes to both academia and practice by applying the constructive research approach on materials flow, tailored for a manufacturing firm. Moreover, an explicit comparison of Lean maturity models is conducted, by this paper's author not found elsewhere, and a new TPS/Lean maturity model is introduced.

Keywords Lean manufacturing, Toyota production system, Operations management, Flow efficiency, Continuous improvements, Setup time reduction, Kanban system, Constructive research approach

Paper type Master's thesis

Sammanfattning

Förbättringar av materialförsörjningsprocesser till produktionslinor genom Toyotas produktionssystem och Lean: En fallstudie hos TePe Munhygienprodukter AB

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Handledare: Professor Andreas Norrman

Syfte – TePe Munhygienprodukter AB (TePe) flyttar i nuläget sin produktion av tandborstar som en del av en expansionsfas. De ser inte bara utmaningar i en ny tvåvåningsanläggning, utan också effektivitets- och säkerhetsmässiga utmaningar i materialflödena. Syftet med det här examensarbetet är att skapa rekommendationer som förbättrar TePe:s materialförsörjningsprocesser till produktionslinor genom Toyotas produktionssystem (TPS) och Lean.

Metodologi – En konstruktiv forskningsmetodologi används för att utveckla problemlösande rekommendationer gällande ovan nämnda tre utmaningar. En tvåfallsstudie genomförs också för att finna förbättringspotential i TePe:s nuvarande materialflöden. Ett omfattande teoretiskt ramverk för TPS/Lean länkar fallspecifik praktik med teori.

Resultat – Detta examensarbete ger sju rekommendationer på hur TePe kan mildra de utmaningar de står inför, och samtidigt förbättra deras flödeseffektivitet genom TPS/Lean, vilka är: ställtids- och satsstorleksreduktion, layoutförändringar, och implementering av ett materialtorg, ett kanbansystem, 5S och, vad denna forskning kallar, ledningsprinciper (i.e. Genchi genbutsu, Kaizen, ”5 varför”, att leda visuellt och en omvärdering av företagets strategier). TePe kan årligen spara 0.74 MSEK i lagerhållningskostnader om man genomför förslaget på en 57-procentig ställtidsreduktion inklusive efterföljande 50-procentiga satsstorleksreduktion. Rekommendationerna ger dessutom en strukturerad materialförsörjningspåfyllnad som helt eliminerar företagets problematiska säkerhetsrisker. Dessutom sker en kedjereaktion av indirekta fördelar genom implementering av alla sju rekommendationer. Ledningens engagemang är en nödvändighet för att sedan främja en ny kultur byggd på kontinuerliga förbättringar och medarbetarintresse.

Originalitet – Detta examensarbete bidrar både akademiskt och praktiskt genom att tillämpa den konstruktiva forskningsmetodologin på materialflöden, speciallt anpassat för ett tillverkningsföretag. En jämförelse, som enligt min vetskap inte tidigare har genomförts, av fem mognadsmodeller för Lean-implementering genomförs, varpå en ny mognadsmodell introduceras.

Nyckelord Lean tillverkning, Toyotas produktionssystem, Verksamhetsstyrning, Flödeseffektivitet, Kontinuerliga förbättringar, Ställtidsreduktion, Kanbansystem, Konstruktiv forskningsmetodologi

Rapporttyp – Examensarbete

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Finally, this research has verified certain personal statements while it has been conducted, one of them being that nothing ever becomes perfect, another that no matter the planning, there is always a hurry as deadline approaches.

Lund, June 2020

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Patrik Östlund

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Abbreviations

CI – continuous improvement
CSF – critial success factor
ENVAA – essential non value-added activity
EP – EasyPick
ERP – enterprise resource planning
HVP – high-volume product
IDB – interdental brush
JIT – just-in-time
KPI – key performance indicator
Lean – Lean manufacturing/production
LT – lead time
LVP – low-volume product
ME – Medical Excellence
MSP – materials supply process
MTO – make-to-order
MTS – make-to-stock
Nolato – Nolato MediTech AB
NVAA – non value-added activity
OEE – overall equipment effectiveness
PACE – prioritization, action, consider and eliminate
PDCA – plan-do-check-act
P-Kanban – production-Kanban
P/M – principle/method
PT – processing time
ROI – return on investment
RQ – research question
SKU – stock keeping unit
SMED – Single-minute exchange of die
TePe – TePe Munhygienprodukter AB
T-Kanban – transportation-Kanban
Toyota – Toyota Motor Corporation
TPS – Toyota production system
UoA – unit of analysis
VAA – value-added activity
VMI – vendor-managed inventory
VSM – Value stream map
VTG – Value vs. time graph
WT – waiting time

Note to the Reader

In Japan, the family name appears before a person's first name. The Americanized way of referring to, for example, the famous founder of the Toyota production system is Taiichi Ohno, even though the custom of his home country is to acknowledge him as Ōno Taiichi (Ohno, 1988). Therefore, similarly to the CRC Press, which translated *Toyota Production System: Beyond Large-Scale Production* into English in 1988, in-text references of this paper introduces Japanese names according to their standards. This is simply done out of common courtesy to Japanese traditions.

Chapter 1. Introduction

This chapter introduces the reader to the main drivers for why this Master's thesis is conducted. There is, first, a short overall background to the research area, followed by a description of TePe as well as their products. Second, specified problems by TePe are described, as well as the purpose of this research and its delimitations. A number of research questions are, then, stated. Finally, a reader's guide to the rest of the paper concludes this chapter.

1.1 Background

As the competition intensifies by global markets in many businesses (Alizon, Dallery, Essafi & Feillet, 2007), companies have to consider, and adopt, new manufacturing approaches to stay competitive (Hall, 1987; Meredith & McTavish, 1992; Shah & Ward, 2003). Suzaki (1985) even acknowledged a revolution in competitive strategy some 30 years ago as progress was made in manufacturing techniques, and to keep up with competition management needed to decide upon methods improving manufacturing capabilities (Suzaki, 1985). This is still pertinent today due to increased rivalry among global businesses (Shah & Ward, 2003).

Many companies have been forced to take action; therefore they have implemented Lean manufacturing techniques (Alizon et al., 2007). By implementing Lean principles, corporations have achieved economic benefits along with improved quality, and reduced costs and cycle times, which are all important elements to stay competitive (Cudney & Elrod, 2011). That Lean production[1] is a well-accepted principle to enhance performance and add a competitive edge is widely recognized among scholars and other professionals (Shah & Ward, 2007).

But what is in fact Lean production? Simply put, Womack, Jones and Roos (1990) define the term as an innovative production system combining the advantages of mass production and craft production. But, as is discussed by several authors such as Bhamu and Sangwan (2013), Petterson (2008), and Shah and Ward (2007), the concept does lack a common definition. To understand Lean production better, we have to consider its origins.

At the end of 1949, the automobile company Toyota Motor Company suffered a loss of sales, whereupon their engineer Toyoda Eiji went to Detroit, USA, to carefully study the production system initiated by Henry Ford, the father of mass production (Womack, Jones & Roos, 1990). Back home in Japan, Toyoda and the production genius Ōno Taiichi developed the concept of

[1] There is no clear definition between Lean production and Lean manufacturing, but different authors seem to

Toyota production system (TPS) (Womack et al., 1990). Ohno (1988) himself defines the basis of *"Toyota production system ... [to be] the absolute elimination of waste"* (p. 9). Later, from that system stems Lean production, which is introduced to North America by Womack et al. (1990). Liker (2004) represents a lean manufacturer as a company striving for a product flow with value-adding activities without interruptions, based on customer demand, which replenishes only what next operation needs, and to have an ever-improving culture.

Lean production is frequently used as a surrogate for TPS (Shah & Ward, 2007). This paper is trying to take the best out of two worlds, but the definition of Lean manufacturing is the same as was introduced to North America many years ago. As discussed by Cudney & Elrod (2011), this means focusing on identifying and eliminating waste and improving materials and information flow by addressing value-added and non-value added activities.

Several researchers have identified that an implementation of Lean gains improvements in production lead times, processing times, amount of inventories, employee morale, standardized housekeeping and effective communication (Bhamu & Sangwan, 2014), to mention a few. Moreover, an implementation provides a safer work environment (see Liker, 2004; Green, Lee & Kozman 2010; Al-Aomar, 2011), including a cleaner workplace (Al-Aomar, 2011).

But to fully understand a company's value stream, it is necessary to map value-added activities (Hines & Rich, 1997). In Lean manufacturing, the most popular way of representing production units to identify production waste is through value stream mapping (VSM) (Dinis-Carvalho, Guimaraes, Sousa & Pinto Leao, 2019). But there exists several visual mapping techniques discussed later in the theoretical framework of this paper. For example, Hines and Rich (1997) present seven tools, two regarded as new at that time, while Kalman (2002) suggests six techniques.

1.2 Company Description

TePe Munhygienprodukter AB (TePe) is a privately held Swedish family business operating in the oral health industry (TePe a). They develop and manufacture oral health products in Malmö, Sweden, and market them worldwide (TePe a). The company aims to have a scientific approach on their product development whereupon they have a close collaboration with dental professionals (TePe b).

It all started in 1965, when wood-carver Henning Eklund and two professors of the School of Dentistry collaborated to develop the triangular stick designed to suit the interdental space between teeth (TePe a). As the business grew, TePe introduced toothbrushes to their product portfolio followed by the renewed TePe Interdental Brushes in 1993, which led to international success, especially in the United Kingdom, Germany and Sweden (TePe a). TePe continued their internationalisation by establishing several subsidiaries globally, and Joel Eklund, CEO from 2012 and grandson of Henning Eklund, continued the expansion (TePe a).

Today, the company exports products to 60 countries, and they have a turnover of 750 MSEK (2018), with 340 employees spread over eight countries (TePe a). They now produce a wide range of oral health products, still having their headquarters in Malmö with all research and production, which gives them control over the value chain (TePe a). TePe strives to increase public awareness of preventative dental care, interdental cleaning and how oral health impacts general health, while their vision is to bring healthy smiles for life (TePe a).

1.3 Product Description

TePe offers a wide range of oral health products categorized in: toothbrushes, interdental cleaning and special brushes (TePe c).

1.3.1 Toothbrushes

TePe manufactures 184 different types of toothbrushes, which all are made of plastic molded handles, but come in many different sizes, models, colours and softness of the nylon filaments (TePe c). A selection of types can be seen in *Figure 1.1*. The case study at TePe is limited to the study of toothbrushes and no other products.

Figure 1.1. The TePe product category toothbrushes (TePe e).

1.3.2 Interdental cleaning

Toothbrushes remove plaque from smooth surfaces; however, they have limits accessing interproximally (Choo et al., 2001), i.e. in the area between adjoing teeth. TePe, therefore, offers a collection of interdental cleaning products (TePe c), as can be seen in *Figure 1.2*. The IDB, which comes in different sizes, models and angels, is a small brush used to clean between teeth, at such places where the toothbrush cannot reach (TePe c).

Figure 1.2. Three types of products from the product category interdental cleaning. From left to right: interdental brushes, toothpicks (EasyPick™) and dental floss (TePe e).

1.3.3 Special brushes

Special brushes are developed for people with special oral hygiene needs, such as the cleaning of wisdom teeth, dental implants or braces. Some types of special brushes is pictured in *Figure 1.3*.

Figure 1.3. A few products from the product category special brushes (TePe e).

1.4 Problem Description

TePe has decided to move their production facility in an expansion phase to both stay competitive in the oral health industry and to continue meeting their objective on 10-20 per cent growth yearly. A growing demand entails increased production and consumption of raw materials at the company (TePe, 2018), which, in turn, demands both efficient production and efficient materials flow in the facility. The majority of workstations in the assembly lines are today automated at TePe. Conçalves & Salonitis (2017) argue that efficient designed workstations are fundamental for decreasing production time, space used and costs. Since TePe has been focusing on the efficiency of the assembly lines, they thereafter had to customize the materials supply processes to the production, which according to Johansson and Johansson (2006) is common in the industry.

Accordingly, TePe is not satisfied with the materials flow to assembly lines in their production facility due to several factors that I discussed in the Introduction section, such as long lead times, high inventories, non-structured replenishment procedures and occurrence of safety hazards. In some materials supply processes today, blue-collar workers refill materials manually from the warehouse. Neither is this an efficient nor a safe method. Even though TePe instructs their workers to take safety precautions when in the warehouse in which forklifts move, these precautions are not followed perpetually. Since TePe now intend to move their production of toothbrushes into a new, bigger facility, they see a reconstruction of materials supply processes possible. In the procedure they need help mapping the materials flow and, based on that, constructing improvement solutions. A possible solution is to construct these recommendations using production methods such as Toyota production system and Lean manufacturing.

1.5 Research Purpose

The purpose of this paper is to improve the materials supply processes to assembly lines in a manufacturing production facility through Toyota production system and Lean manufacturing, and recommend TePe on improvements in their expansion phase.

1.6 Focus and Delimitations

The scope of this paper is limited to internal materials supply processes to assembly lines in a manufacturing production facility. Assembly lines are production systems with serially located workstations, in which parts are added to a semi-manufactured assembly, but in this paper it also includes final packing of products into secondary packaging. At TePe, this paper is delimited to materials flow for one product category, the toothbrush, illustrated in *Figure 1.4*. The supervisor at TePe narrowed the scope down to fit the time-constraints within a Master's thesis.

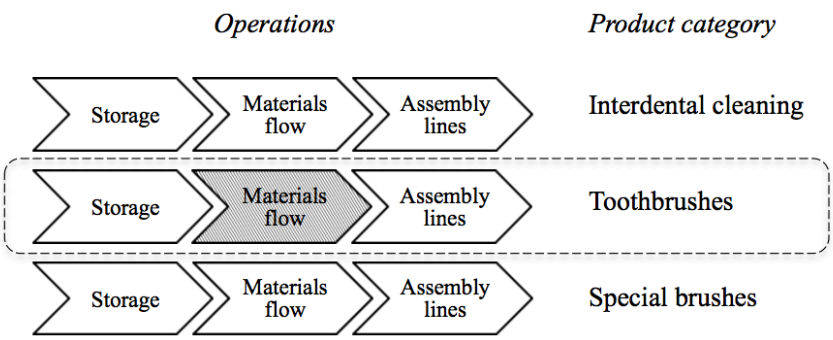


Figure 1.4. Delimitations of the case study at TePe.

1.7 Research Questions

This paper is built upon three research questions developed in collaboration with TePe. They are constructed around three different aspects, i.e. efficiency, safety and the new production facility. The research questions are presented below.

RQ1	*How can materials supply processes to assembly lines at TePe be improved by implementing Toyota production system and Lean?*
RQ2	*Why is the materials supply processes at TePe bringing safety hazards? How can these safety hazards be minimized?*
RQ3	*How should raw materials be supplied to the new production facility?*

1.8 A Reader's Guide

This is a quite comprehensive Master´s thesis, and, thus, I have divided it into sections in order to give the reader an understanding of its structure. Based on interest, the reader can, in that way, immerse oneself in the section(s) most relevant.

Chapter 2-3	These chapters are this paper's academic section, including both a theoretical framework and the methodology used. This section should be read by anyone with an interest either in the theory of TPS/Lean or in assessing the quality of the paper. For further clarification on how sections relate to each other, a contextual scheme of the Master's thesis concludes *Chapter 3*.
Chapter 4	This chapter is an AS-IS analysis of the materials supply processes at TePe. The chapter can, however, be further divided into following sub-sections: (1) description of current production facility, (2) evaluation of current production facility and (3) current TePe challenges. Prioritized challenges, then, conclude *Chapter 4*. The reader not well acquainted with the TePe business should read this chapter. The second half of the chapter is appropriate for any TePe employee interested in their improvement possibilities.
Chapter 5-6	This section describes TePe's implementation of TPS/Lean principles thus far, and compares the efforts with a company publicly noticed for their Lean commitments. This section should be read by anyone

interested in a TPS/Lean implementation in a manufacturing company.

Chapter 7-8 These chapters are closely interrelated, since they either explain or recommend the constructs of this paper. The section is based on challenges found in *Chapter 4-6*. Many of the constructs developed in *Chapter 7* also have implementation guides appended for the interested reader. *Chapter 8* addresses the economic aspects of an implementation. This section should be read by anyone interested in the results of this Master's thesis.

Chapter 9 This section concludes the results of the paper. Future development and research, both for TePe and for academia, closes the paper. This section should be read by the impatient reader, or the reader searching for ideas to further research.

In summation, the reader who is already briefed of this paper's aim and has a clear insight of the challenges TePe faces may find an interest in starting their read from *Chapter 7*. My recommendation is, however, to, at least, start a reading from *Chapter 4*, since this will give the reader a thorough understanding of the foundation of this paper.

Chapter 2. Theoretical Framework

This chapter represents the theoretical foundation of which this paper is built on. Initially, an outline of what the reader can expect from the rest of the chapter is presented. Then, materials supply processes are discussed briefly, followed by the basis of this theoretical framework, which is values, principles and methods from Toyota production system and Lean. Finally, critical success factors in regard to a TPS/Lean implementation are discussed.

2.1 Outline of Chapter

For a better understanding of the frame of reference used in this paper, *Figure 2.1* is initially presented. *Values* represent how a company should last (Modig & Åhlström, 2012); how they should think, behave and act in all situations. The *values* serve as the culture of a company (Modig & Åhlström, 2012). *Principles,* then, are the guidelines of the values. Modig and Åhlström (2012) define the principles as how decisions should be made within an organisation, and what to prioritize. Basically, the values are implemented through principles (Modig & Åhlström, 2012). Moreover, *methods* are what a company do and how it is done (Modig & Åhlström, 2012), all through the basis of their principles. Finally, *tools & activities* are what is needed to perform the methods (Modig & Åhlström, 2012). This could include personel, machines or other tools.

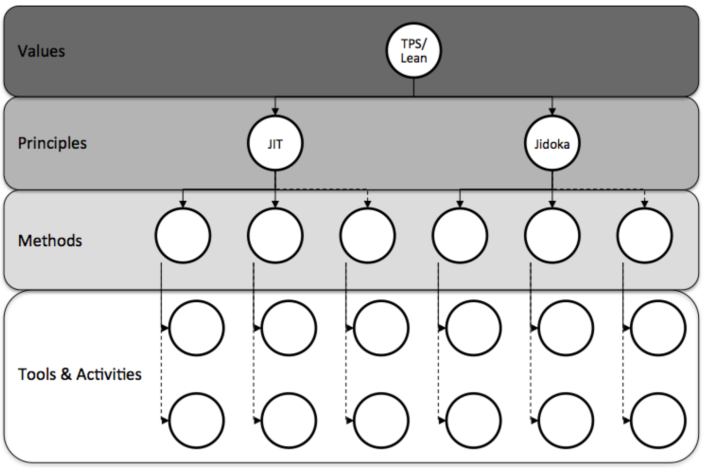


Figure 2.1. Structure of how a company is built, and the pillar stones of Toyota production system and Lean. Based on Modig and Åhlström (2012), pp. 140.

The theoretical framework of which this chapter is built on is depicted in *Figure 2.2* below. As can be seen, the framework is divided into a similar structure shown in *Figure 2.1*. The color system connects the two figures.

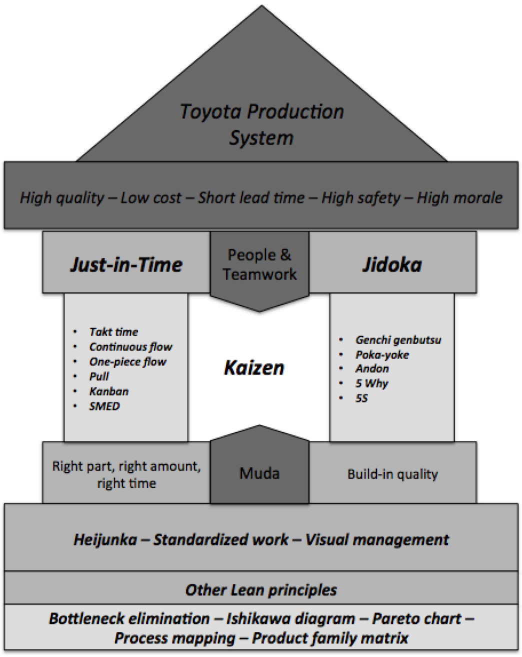


Figure 2.2. The theoretical framework in this paper, often mentioned as the Toyota production system (TPS) house. The framework is mostly based on Liker (2004), pp. 33, but also on Olhager (2013), pp. 452, pp. 459-484.

The structure of the framework is one of the most recognizable in modern manufacturing (Liker, 2004), and is often mentioned as the *TPS house* (Liker, 2004; Olhager, 2013). The framework has different versions, but the core principles are always the same (Liker, 2004). There is a house, which needs a strong roof (i.e. goals and values), and solid pillars and a steady foundation (i.e. principles and methods) (Liker, 2004).

The values of this Master's thesis are gathered from the Toyota production system and Lean, in which there is a focus on high quality, low cost, short lead time, high safety and high morale. Thereafter, the house is built on principles and methods used in TPS/Lean. The outer pillars of the house are *just-in-time (JIT)* and *jidoka (i.e. in-station quality)*, with their respective methods. There are also various foundational elements including *heijunka (i.e. leveled production), standardized work, visual management* and *other Lean principles*, with their methods. Finally, in the center of the house are essential values such as *People & teamwork* and *muda (i.e. waste reduction),* which both always strive for *kaizen (i.e. continuous improvement).*

A detailed outline of the entire chapter is illustrated in *Figure 2.3*, due to the comprehensiveness of this theoretical framework. Each principle is described followed by its own methods through the chapter. Finally, a research model is presented to be used in structuring the multiple case study descriptions and their analysis.

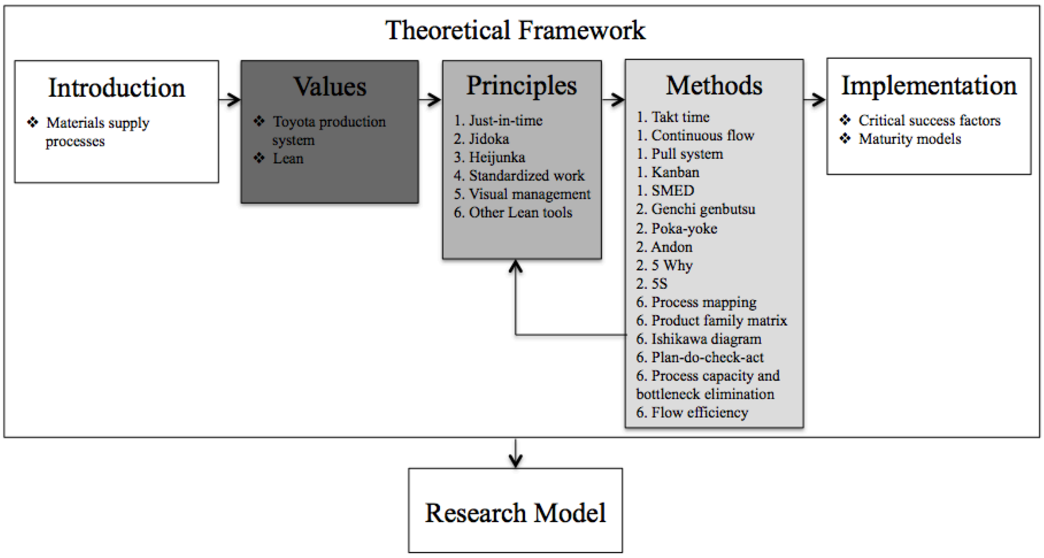


Figure 2.3. A detailed outline of the theory chapter.

2.2 Materials Supply Processes

Movement of all sort of materials is a crucial aspect in todays global manufacturing systems (Davies, Thomas & John, 2014). Modern manufacturing systems should, therefore, be gently designed to minimize the amount of movement both externally and internally (Davies et al., 2014). In fact, materials supply is generally given low priority in industries today (Johansson & Johansson, 2006). Johansson and Johansson (2006) also states that a sound material supply system is even more important when demand increases and the product portfolio is expanded.

Some literature, however, only accounts for internal transportation or the actual handling of material when discussing *materials handling* (Johansson & Johansson, 2006). Johansson and Johansson (2006), instead, divide the materials supply system into six different areas: *(1) materials feeding, (2) storage, (3) transportation, (4) handling, (5) packaging* and *(6) manufacturing planning and control.* The areas are strongly related to each other (Johansson & Johansson, 2006). These are important aspects in the design and implementation of entire production systems (Johansson & Johansson, 2006).

2.3 Toyota Production System

Toyota and their production system caught the world's attention first in the 1980s (Liker, 2004). They manufactured more reliable cars even faster than in other countries, at a competitive cost, even though Japanese workers earned relatively high wages (Liker, 2004).

A first comprehensive look into the way Toyota works in terms of philosophy, processes, people and problem solving occured in 2004 with Jeffrey Liker's publication *The Toyota Way*

(Martin and Osterling, 2014). However, Ōno Taiichi, founder of *Toyota seisan hoshiki*[2], published *Toyota Production System: Beyond Large-Scale Production* already in 1988 with several sturdy tips from Toyota manufacturing facilities, even though the publication does lack a general implementation process. But that may be because TPS according to Ohno (1988) is not just a production system, but a management system. The system has been introduced in companies regardless of industry, scale and nationality (Ohno, 1988). The main aim of TPS is to increase production efficiency by eliminating waste thoroughly and consistently (Ohno, 1988). Waste, basically, is *"anything that does not add value to the product or service, whether material, equipment, space, time, energy, systems, or human activity of any sort"* (Hall, 1987, p. 24).

So, how does Toyota apply this system? Ohno (1988) simply explains that *"[everything they] are doing is looking at the time line"* (p. ix) between order and cash, and, then reduce the time line by removing waste.

2.4 Muda

Muda is the japanese word for waste. An initial step towards an application of TPS is to identify all wastes (Ohno, 1988). But to be able to recognize waste, it is important to understand its nature (Ohno, 1988). Ōno Taiichi (1988) was first to name the seven categories where waste could arise in production, namely in:

- *Overproduction*. A company produces items for which there is no order, or they are producing more than necessary (Liker, 2004; Olhager, 2013).
- *Waiting*. Machines, equipment or tools are not available when needed (Olhager, 2013), which also forces operators to wait for next processing step, or a tool, part etc. (Liker, 2004). Operators may even be waiting because of equipment downtime, capacity bottlenecks, delays or stock-outs (Liker, 2004).
- *Unnecessary transportation.* Products are often moved in-between workstations, which in the layout could have been arranged closer to each other (Modig & Åhlström, 2012; Olhager, 2013). Basically, there can be long distance transportations of work-in-process (WIP), but unnecessary transportation is also, de facto, all movement of materials, parts or finished goods between workstations or in and out of storage (Liker, 2004).
- *Overprocessing*. Needlessly complex activities, which could be done simpler (Modig & Åhlström, 2012; Olhager, 2013). Also, inefficient processing due to poor equipment or tools (Liker, 2004).

[2] Japanese name of Toyota production system (Ohno, 1988)

- ❖ *Excess inventory*. Inventory that exceeds what is absolute necessary to meet demand (Olhager, 2013). This can be excess raw material, WIP or finished goods (Liker, 2004), and it hides problems (Modig & Åhlström, 2012).
- ❖ *Unnecessary movement*. Any motion of an operator is waste, such as looking or reaching for tools, material or help (Liker, 2004; Olhager, 2013). Even walking in itself should be unnecessary, and is considered a waste (Liker, 2004).
- ❖ *Defects*. Producing defective parts (Liker, 2004). There can be incorrect work instructions (Olhager, 2013), causing scrap, rework or extra inspection, which means wasteful handling, time and effort (Liker, 2004).

Ōno Taiichi considered overproduction to be the fundamental waste, since it causes many of the other six wastes (Liker, 2004). Overproduction leads, by definition, to a build-up in inventory somewhere downstream (Liker, 2004), probably in the production facility. A mass producer may ask why this is a problem, as long as, they say, operators and machines are producing parts (Liker, 2004). Besides more obvious reasons such as opportunity costs of tied-up capital and investment costs in warehouses larger than necessary, Liker (2004) explains that inventory between processes leads to suboptimal behaviour. It reduces an operator's motivation to continuously improve processes (Liker, 2004). Why should he worry about an equipment shutdown, when it does not immediately affect the final assembly (Liker, 2004)? Why should he worry about some defects scrapped downstreams, when it does not immediately affect the operations (Liker, 2004)?

However, the seven wastes are all connected to each other, and often hidden in the complexity of a large organization (Hall, 1987). Why different wastes are a problem and possible solutions to them when encountered can be seen in *Table 2.1* below.

Table 2.1. Seven wastes and why they are undesirable as well as possible solutions to minimize them. The second row is based on Liker (2004), pp. 28-29, while the third row is based on Hall (1987), p. 26.

Wastes	*Overproduction*	*Waiting time*	*Unnecessary transportation*	*Overprocessing*	*Excess inventory*	*Unnecessary movement*	*Defective products*
Why a problem?	– Causes the other six wastes – Overstaffing – Extra storage costs – Extra transportation costs	– Processing delays – Operators not working – Excess inventory	– Time consuming	– Producing defects – Unnecessary motion – Over-quality is unnecessary	– Longer lead times – Obsolescence – Possibly damaged goods – Extra storage and transportation costs – Delays – Tied-up capital – Hides problems, such as late deliveries from suppliers, defects, equipment downtime and long setup times	– Creating ineffecient flows	– Time (repair and inspection) – Cost (Rework, scrap, extra personell hours, customer dissatisfation)
Possible solutions	– Reduce setup times – Adjust timing and quantities between processes – Visibility (through e.g. production smoothing and value stream mapping) – Compact the production facility layout – Produce what is needed	– Production leveling – Synchronize work flow – Balance uneven workload by flexible workers	– Build a layout that minimizes transportation – Rationalize why transportation is necessary	– Use 5 whys: Why is the part/product made? Why is the process necessary?	– Reduce lead times and setup times through (1) synchronized work flows, (2) improving work skills and (3) production leveling – Achieve one-piece flow – Reduce all other *wastes*	– Motion studies. First, improve the motions and, then, automate (otherwise waste is automated) – Layout	– Achieve perfection (zero defects) by inpection and Poka-yoke – Improve production processes in such a way as to eliminate inspection (make processes failsafe) – Kaizen (accept no defects) – Jidoka

2.5 Lean Manufacturing (or just Lean)

Some authors question Lean to be a *"repackaged version of a previously popular method"* (Näslund, 2013, p. 86), i.e. a derivative of TPS (see Dahlgaard & Dahlgaard-Park, 2006; Näslund, 2013). Others may say that Lean manufacturing is merely a production method to minimize waste, and, in turn, create value (see Botti, Mora & Regattieri, 2017). However, it cannot be emphasized enough that Lean, or TPS, is not only a tool kit (Liker, 2004). It is much more than Lean tools and techniques such as the *Kanban system*, *5S*, *5Whys* etc. Instead, Liker (2004) argues that it is, like TPS, a sophisticated system in which all parts contribute to the whole. Additionally, it is a widely used change philosophy (Näslund, 2013).

Lean production was first mentioned by researcher John Krafcik in 1988, who participated in the International Motor Vehicle Program (IMVP) studying the car industry internationally (Womack et al., 1990). Womack et al. (1990) explains Lean production to be "lean" because it, basically, uses less of everything in comparison to mass production (Womack, et al., 1990). Womack and Jones (1996) discusses five Lean principles: *(1) value, (2) the value stream, (3) flow, (4) pull* and *(5) perfection.*

- *Value.* The ultimate customer defines the value.
- *Value stream*. The set of activities that bring the product through the company.
- *Flow.* Flow is created by focusing on the value creating activities.
- *Pull.* By establishing a pull system, the customer gets the product when actually needed.
- *Perfection.* Improvement is a continuous activity to bring value to customers, and, therefore, a Lean company always seek for perfection, i.e. to continually strive to decrease costs, manufacture zero defects, hold zero inventory and have an endless product variety (Womack et al., 1990).

Activities within a value stream can be further divided into three categories (Liker, 2004; Olhager, 2013), describing the value to customer: *(1) value-added activities, (2) non value-added activities* and *(3) essential non value-added activities.*

- *Value-added activities (VAA)*: Anything that adds value to a product (Hall, 1987; Ohno, 1988), i.e. the actual transformation processes (Liker, 2004). Ohno (1988) and Olhager (2013) exemplifies with activities that create a change of shape and leads to the completion of a product.

- *Non value-added activities (NVAA)*: Basically, this is everything not adding value (Hall, 1987), such as transportation, storage, inspection, testing etc. (Olhager, 2013). Some may say that such activities are VAA, since they make the product available for the customer (Olhager, 2013)[3]. But in the conventional sense, those activities are regarded as *waste* (Ohno, 1988). The conditions need to be partially changed to eliminate them (Ohno, 1988).
- *Essential non value-added activities (ENVAA)*: All activities that support effective transformation processes of a product (Olhager, 2013). Examples are information-based activities such as *planning* and *forecasting* (Olhager, 2013).

When used to its full extent, Lean even goes outside of the production facility and also integrates suppliers in joint activities, such as, value analysis to reduce costs, information sharing, establishing prices and agreements on sharing profits (Womack et al., 1990).

There are several process enhancement tools related to TPS/Lean, which is discussed in more detail in the following sections. However, the centrality of people is missed if only focusing on the tools. The people might not understand the culture behind TPS (Liker, 2004). Having that said, a company shall strive for implementing the whole concept, rather than specific tools.

2.5.1 Industry appropriateness

Liker (2004) briefly discusses which businesses Lean applies to, since many practitioners often think that Lean cannot be applied to their company. However, Lean is not about imitating the manufacturing processes at Toyota, but rather about developing principles for any organization, and, then, practice them relentlessly to be competitive and add value to customers (Liker, 2004). Thus, according to Womack et al. (1990), the principles of Lean production can be applied to every industry (Womack et al., 1990). Womack et al. (1990) may be biased in their statement, since the appropriateness of Lean implementations in different organizations is a matter for debate (see e.g. Christopher & Towill, 2000; Näslund, 2013).

2.5.2 Characteristics appropriateness

In fact, Näslund (2013) concludes that specific change efforts are not equally appropriate for every company in every industry. An organization with high production volumes is, for example, likely to be more successful after a Lean implementation (Näslund, 2013). However, a high degree of customization and variability can cause some disturbances though (Näslund, 2013). A Lean

[3] However, if the production lead time is shorter than the time a customer expects the delivery, the product could have been manufactured when the customer order was received. Therefore, such activities here are regarded as NVAA.

implementation works best when the strategy to reach competitiveness is based on customer drivers such as cost (see Christopher & Towill, 2000; Hallgren & Olhager, 2009). When the market winner instead is service level, other initiatives such as *Agile manufacturing* is more appropriate (see Christopher & Towill, 2000; Hallgren & Olhager, 2009). Another distinguishing attribute for products in an Agile inititative is high profit margin (Christopher & Towill, 2000)[4]. Moreover, a key characteristic of a Lean production is that it is *repetitive* (Hallgren & Olhager, 2009).

2.6 Kaizen

No process is ever perfect, so there is always room for improvements (Olhager, 2013). *Kaizen* – the philosophy of continuous improvements – is, therefore, paramount to TPS/Lean because all other principles and methods revolve around improvement.

There is an ambition to always strive for perfection – a perfect conformity to specification is realistic in all cases (Schonberger, 1983). Kaizen is that total philosophy of striving for perfection (Liker, 2014). Basically, it is the process of doing incremental improvements, regardless magnitude, in the endeavor to eliminate waste (Liker, 2004). All employees should try to improve processes all the time (Olhager, 2013). Liker (2004) mentions that kaizen consists of everything from *(1) teaching skills of problem solving*, *(2) working effectively* and *(3) documenting*, to *(4) analyzing data* and *(5) self-managing*. This, in turn, pushes a lot of responsibility onto the workers (Womack et al., 1990). The people are the ones driving continuous improvement (Liker, 2004).

2.7 People & Teamwork

The unquestionable essence of the Toyota philosophy is the culture, and the culture needs to support the people doing the work (Liker, 2004). It starts with upper management, who needs to be commited to their goals (Liker, 2004). But ultimately, it is the blue-collar workers who fulfill goals such as quality (Liker, 2004). First telling people they are important, but then risk their health and safety to reach production goals is doomed (Liker, 2004). Everything starts with pushing responsibility down the organization (Womack et al., 1990).

Motivation methods are often used in TPS/Lean to motivate associates (Liker, 2004). At Toyota, five essential motivation theories have been used for this purpose (Liker, 2004). These are not only external-driven theories, but internal-driven as well (Liker, 2004). The external-driven theories assume that people are motivated by *(1) reward, (2) punishments* and *(3) goal setting* (Liker, 2004). The internal-driven theories, however, focus on *self-actualization* through employees moving in hierarchy, and *job enrichment* through, for example, a safe and attractive work environment (Liker, 2004).

[4] Such principles are, however, not within the area of this paper's scope, and are not further evaluated.

To fully master TPS/Lean, a company needs to move outside of their facility and incorporate suppliers and customers. This extended network helps companies to improve and challenge each other (Liker, 2004). Since plants strive for high-quality JIT deliveries, a company needs their suppliers to be as capable as they are (Liker, 2004). Collaboration for mutual learning is, thus, important (Liker, 2004).

2.8 Just-in-Time (JIT)

JIT is the skeletal structure of TPS, and was the starting point of the system (Ohno, 1988). The aim is that the right parts reach the right location in the right amount and at the right time (Ohno, 1988). The name of the method emphasizes the philosophy; no parts shall arrive earlier – this means waste due to increased costs for inventory and space used, as well as extra managing of parts (Ohno, 1988). Needless to say, no parts shall neither arrive later than *on time* (Ohno, 1988). Shingo (1984) illustrates these time management procedures with a train and a passenger: The passenger wants to be at the train station on time to catch the train, but not too early due to waiting time; however, the passenger will not get a seat if the train is full (p. 122), which means even more waiting time. If a company accomplishes a flow through JIT, they can approach zero inventory (Ohno, 1988; Shingo, 1984).

2.8.1 Continuous flow

A continuous flow lowers the ”water level” of inventory and, in turn, exposes problems that need to be fixed (Liker, 2004). A true one-piece flow is what TPS theoretically aims for, since this would, according to Liker (2004), result in a zero-inventory system with goods appearing when they are needed. A one-piece flow, for example, creates an in-build quality, real flexibility, free up floor space and improves safety (due to smaller batch sizes and less forklifts transportation) (Liker, 2004).

The one-piece flow is, however, not always possible due to processes being too far apart or variations in cycle times (Liker, 2004). Instead, a company should walk by the motto to flow where they can but to pull where they must (Rother & Shook, 1999). The second best thing is to arrange a pull system with some inventory (Liker, 2004).

2.8.2 Pull system vs. push system

A multi-step production system involves several processes with either *pull* or *push* methods (Ohno, 1988). The push method is widely used in industry (Ohno, 1988; Liker, 2004); when used all through often referred to as *mass production*. By utilizing *inventory on hand* and *demand predictions,* production quantities are planned (Ohno, 1988; Liker, 2004). Essentially, the products are pushed from the first process to next and so on (Ohno, 1988), and then out on the market. A pull method, on the contrary, does not look at transfer of materials in the conventional way, but in the reverse order (Ohno, 1988). It starts from the final process withdrawing needed quantities from preceding process at specific times (Ohno, 1988). TPS is such a pull system (Ohno, 1988). Other examples of pull-based stock control systems are reorder point system (ROP) and material requirements planning (MRP). However, these are built upon several assumptions such as guessing the demand for production planning, guessing production lead times etc. (Schonberger, 1983). The systems count on daily adjustments in the production plant (Schonberger, 1983; Persson, 1996). Besides, bad guessing often leads to high inventories (Schonberger, 1983). Moreover, research show that throughput times often are 30 to 150 per cent longer than planned (Persson, 1996). ROP is actually the dominated system in companies, leading to long throughput times, typically with weeks or months of stock-value (Schonberger, 1983). A pull method, generally, avoids wastes such as *overproduction* (Liker, 2004). This, in turn, decreases tied-up capital and frees up space, as well as reduces costs of storing excess inventory. It also increases both *flexibility* and *customer satisfaction* due to the ability to customize products (Persson, 1996).

2.8.3 Kanban system

Since *JIT* builds upon *"right parts and right amount at the right time"*, there is of importance having a method that supports the pull system. *Kanban* is such a method. Basically, Kanban is a simple and visual tool that TPS uses to request components when needed (Olhager, 2013), but without guessing (Schonberger, 1983). The kanban system is based on cards, signaling preceding processes what needs to be produced or replenished (Persson, 1996). There are two types of kanban; one for transportation (T-kanban cards) and one for production (P-kanban cards) (Persson, 1996; Schonberger, 1983; Mattsson & Jonsson, 2003). In *Figure 2.4*, the different cards are illustrated with important parameters to include when designing them.

Transportation kanban

Identification of article (art. nr., name etc.)
Card number (e.g. 6/10)
Container capacity
Storing place
From (department, process, machine etc.)
To (department, process, machine etc.)

Production kanban

Identification of article (art. nr., name etc.)
Card number (e.g. 6/10)
Container capacity
Raw material
Tools
Minimum number of cards to start production
Maximum number of cards to start production
Storing place
From (department, process, machine etc.)
To (department, process, machine etc.)

Figure 2.4. Example of parameters to involve in transportation and production kanban cards. Based on Mattsson and Jonsson (2003), p. 412.

There are also different approaches to the kanban system (Graves, Rinnooy Kan & Zipkin, 1993). But if both T- and P-kanbans are used, it is called a *dual kanban system*; otherwise a *single kanban system* (Persson, 1996). P-kanbans circulate within the production cell, while T-kanbans circulate between cells, such as the warehouse and production (Mattsson & Jonsson, 2003). A dual kanban system is illustrated in *Figure 2.5*.

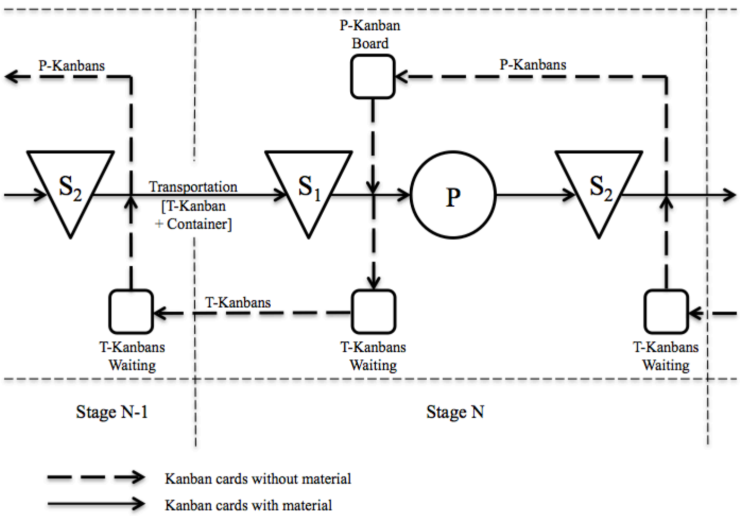


Figure 2.5. A simplified overview of the dual kanban system and the flow of kanban cards. Based on the model presented by Harry Groenevelt (Graves et al., 1993, p. 647).

First consider the P-kanbans circulating within a production cell in *Figure 2.5*. When production of a lot starts, the P-kanban is taken from the *P-kanban board*, initiating production of that particular lot, and then follows the same lot through *production* (P) to *output store* (S_2). When the products are finished in Stage N, the P-kanban detaches from the lot and travels back to the P-kanban board. Since the P-kanban is not attached to its standard amount of product, but instead posted on the board, it signals a need of replenishment of *output store* (Graves et al., 1993). The kanban boards show all up-coming production, making it visible to both operators and management (Graves et al., 1993).

Secondly, we look at the T-kanbans in *Figure 2.5*, which have the role of initiating *transportations* (Graves et al., 1993). T-kanbans obviously travel between consecutive stages, and, therefore, there can be several queues of detached T-kanbans. There can be one queue in *Stage N* waiting on transportation over to *Stage N-1*. There can also be a queue in *Stage N-1*, waiting on either a lot or transportation over to *Stage N*. After transportation, the T-kanban is attached to the lot in *input storage* (S_1) until the production of that lot starts, initiated by a P-kanban from the kanban board.

There are a number of ways to organize the transportation function (Graves et al., 1993). Either there can be a *fixed interval system*, which means that pick-ups are done every hour or half hour, or there can be a *fixed quantity system* (Graves et al., 1993). The latter means that a pick-up is done when a pre-determined quantity is reached (Graves et al., 1993).

The Kanban system also leans on some basic rules that needs to be followed: (i) no production can be initiated without a P-kanban card, (ii) neither can there be any transportation without a T-kanban card and (iii) all material being part of the system has a kanban card attached (Graves et al., 1993).

2.8.3.1 Number of kanban cards.

To calculate the necessary amount of cards, aspects such as *lead times for replenishment* and *safety stocks protecting against variations* need to be taken into consideration (Mattsson & Jonsson, 2003). Ideally, the production order quantity and the transportation order quantity are the same as the standard container quantity (Mattsson & Jonsson, 2003). If not possible, multiples of the standard container quantity can be used for P- and T-kanban cards (Mattsson & Jonsson, 2003). Moreover, the number of kanban cards decides the amount of WIP (Persson, 1996). Mattsson and Jonsson (2003), and Monden (1983) present the same way of calculating the number of kanban cards for an article in *Equation 1*.

$$y = \frac{D * L * (1 + \alpha)}{a} \quad (1)$$

where $y =$ number of kanban cards

$D =$ demand per time unit

$L =$ average lead time

$\alpha =$ safety coefficient

$a =$ quantity in a container

The determined number of cards is the upper limit of possibly produced products, which creates visibility of how much actually can be stored in inventory (Yamashina, 1982; Shingo, 1984; Matsson & Jonsson, 2003). Moreover, the goal at Toyota was, at the time, to not exceed a safety stock factor, α, of 0.1 and to not have larger containers than 10 per cent of the daily consumtion (Mattsson & Jonsson, 2003).

However, Shingo (1984) argues that the number of kanban cards is less important; a far more important question is how to improve the production facility to reduce y to a minimum. In other words, Shingo (1984) suggests that there is a possibility to implement too many kanban cards as long as the company gradually decreases the number of cards to find bottlenecks. Starting to implement kanban also leads to a simplification of adminitrative procedures (Shingo, 1984).

2.8.3.2 Kanban appropriateness

Kanban can be used in any manufacturing industry, but ought to be part of some kind of a JIT system (Schonberger, 1983). There is, however, no effect of a kanban system if the setup times are remarkably high, such as several hours, and there are large batch sizes (Schonberger, 1983; Mattsson & Jonsson, 2003). It is, therefore, important to cut both (Schonberger, 1983). The system also works best with a quite steady demand (Mattsson & Jonsson, 2003), when the numbers of defects are low and the equipment is reasonably reliable (Graves et al., 1993). But if kanban is implemented correctly, there is a minimum number of components stored in the production area, since replenishments occur just in time (Olhager, 2013).

2.8.4 Takt time

Takt time is the heart beat of the production (Liker, 2004; Olhager, 2013). It is the German word for *rhythm* or *meter* (Liker, 2004), and is, basically, the rate of customer demand – the rate at which customers buy products (Liker, 2004; Olhager, 2013). The *takt time* is closely related to the *one-piece flow* and *continuous flow*. Optimally, in a *one-piece flow,* every process step should produce according to *takt time* (Liker, 2004). Otherwise products are either piling up (process faster than takt time) or creating a bottleneck (process slower than takt time) (Liker, 2014). Ohno (1988) demonstrates this with the story of the hare and the tortiose. The slow and consistent tortoise does not cause waste and is preferable to the much faster short-range hare (Ohno, 1988), which stops in-between processes to catch its breath. Everybody needs to become tortoises (Ohno, 1988).

Furthermore, takt time determines the flow rate, and makes it possible to calculate the capacity of the production (Olhager, 2013). The idea is to create a balanced flow through the production facility (Olhager, 2013). The concept of takt time is easiest to apply to repetetive operations with high-volume products (Liker, 2004). In turn, this reduces waste and flow efficiency (Olhager, 2013).

2.8.5 Single minute exchange of die (SMED)

Setup *time* is the time there is between *the last processed non-defected part within the lot* to *the first processed non-defected part within the next lot* (Olhager, 2013). This means that all time for adjustments of a machine also is part of the setup time (Olhager, 2013). With shorter setup times, smaller lots can be allowed (Yamashina, 1982). In turn, smaller setup times provides benefits such as not only flexibility, but less WIP, shorter throughput times, shorter lead times to customer, less defects (defects are found faster) and making it easier to prioritize (Yamashina, 1982).

Single Minute Exchange of Die (SMED) is a usual method for reducing setup times (Olhager, 2013). Both Persson (1996) and Olhager (2013) emphasize that the overall objective is to reduce setup times to no more than ten minutes, hence the name of the method. The designer of the method is Shigeo Shingo (Shingo, 1984; Olhager, 2013). The method is based on separating between setup times, which are *inside* and *outside* of a machine. The aim is, then, to continuously convert as much of the *inside work* into *outside work*, which *Figure 2.6* illustrates.

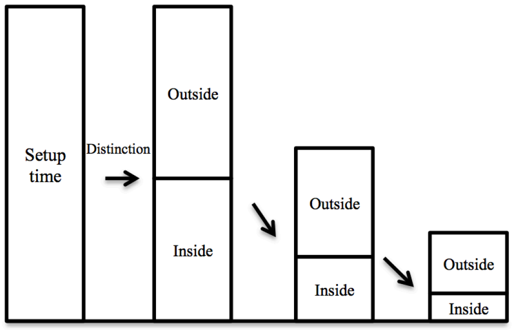


Figure 2.6. The methodology of how SMED works. Retrieved from Yamashina (1982), p. 19.

Shingo (1984) established an eight-step-process for reducing setup times:

1. *Separate between Inside Exchange of Die (IED) and Outside Exchange of Die (OED).* OED (tools, jigg and fixtures, material etc.) should be perfectly structured next to the machine (Shingo, 1984). OED activities refer to activities that can be executed while the machine is active (Yamashina, 1982; Olhager, 2013). IED activities refer to activities that require the machine to be stopped (Yamashina, 1982; Olhager, 2013).
2. *Convert IED to OED.* This step often requires some ingenuity (Yamashina, 1982). Methods of how to do the conversion follow in step three to eight.
3. *Functional standardization.* Standardizing the shape and dimension of tools often facilitates setups (Shingo, 1984). But more importantly is to standardize the dimensions that are essential for tool attachment (Shingo, 1984). Shingo (1984) examplifies that all tools should have the same clamping height. In turn, the same clamps can be used everywhere (Shingo, 1984).
4. *Functional clamps.* Clamps should be constructed in such a way that they require minimum time and effort (Shingo, 1984). Say, for example, that a bolt has 15 threads, it needs to be turned 14 times before it tightens on the last turn (Yamashina, 1982). Such an arrangement may be re-arranged depending on the requirements of clamping force (Yamashina, 1982).
5. *Pre-adjusted fixtures.* The up-coming tools can be attached on standardized fixtures while the machine is still processing the previous lot.
6. *Parallel operations.* Two operators work in parallel during the setup (Yamashino, 1982). For example, tools for injection moulding consists of two plates (injection mould and erector mould). If such plates can be attached in parallel, Shingo (1984) argues that the attachment time can be reduced by 2/3.
7. *Eliminate adjustments.* According to Shingo (1984), adjustments take up 50-70 per cent of IED. Adjustments can be divided into *positioning* (e.g. moving from 150 mm to 200 mm) and *adjusting* (e.g. moving back and forth until desired result is achieved) (Shingo, 1984). All adjusting should be removed (Shingo, 1984).

8. *Mechanization.* Mechanization of the setup process should be used only when the first seven steps have been implemented already.

Olhager (2013) recommends each company experiencing some issues with setup times to do a business case in which they analyze setup times. Because if these eight steps are used, Shingo (1984) emphasizes that setup times will be decreased by 67 to 90 percent. Ohno (1988) further clarifies that Toyota managed to decrease their setup times from two to three hours into three minutes (i.e. with more than 97 per cent).

2.9 Jidoka

Jidoka is the second pillar stone in TPS (Liker, 2004). The principle is often referred to as *autonomation* – that is applying human intelligence into machines to stop them when there is a problem (Ohno, 1988; Liker, 2004; Modig & Åhlström, 2012; Olhager, 2013). Basically, the principle is based on methods of automatically stopping production when a problem occurs, requiring the operator to fix the problem and, by doing so, preventing defects flowing downstreams (Liker, 2004) creating even more damage through tied-up capital.

Modig and Åhlström (2012) use a football reference when describing jidoka. If JIT is the flow of the ball, the flow of players and their collaboration, they say jidoka is not only the rules but the pitch itself with its lines, with the players, the scoreboard and the referee's whistle (Modig & Åhlström, 2012). Everything is visible for the players, and the same should be true for an organisation. Moreover, if a player commits a foul, the referee blows her whistle. That should also be true within an organisation. Therefore, jidoka is the countermeasure of JIT.

Jidoka focuses on creating an organisation that is visible enough to identify anything that impedes or interferes with the flow (Modig & Åhlström, 2012) to eliminate it immediately. There is no room for compromises in terms of quality in TPS, and therefore, jidoka builds upon quality controls in every step in the production process (Olhager, 2013). Every team member has a responsibility to do a quality inspection before next workstation (Olhager, 2013). Even though it means a temporary stop in production (Olhager, 2013), it is essential for equipment to stop immediately if there is any possibility for defects (Ohno, 1988, Olhager, 2013). Therefore, jidoka is the other side of the JIT coin (Modig & Åhlström, 2012), the countermeasure to smooth flow.

2.9.1 Genchi genbutsu

Genchi genbutsu is Japanese for *"real location, real thing"*, but Liker (2004) with many other authors who have been in the business of Toyota interpret it as *"go and see for yourself to thoroughly understand the situation"*. This is part of jidoka, since it contributes to a better visibility.

Also, the real issues need to be understood before improvements actually can be done (Olhager, 2013).

Liker (2004) exemplifies genchi genbutsu with the *Ohno Circle* – in which employees have been forced, according to the many stories, to stand in a circle for several hours, just to *"watch for themselves"*. Obviously, data is important in manufacturing, but Ōno Taichii emphasizes that the data is merely indicators of what is going on, one step removed from the actual processes (Liker, 2004). Ohno (1988) stresses the importance of going to the heart of the matter, but also to have a a chessplayer's overview of the entire picture.

As there is of importance to pass on information out of personally verified data, genchi genbutsu is essential (Liker, 2004). But since time is finite for many managers, at least *hourensou* can be used (Liker, 2004). Hourensou is a method for, especially, senior management to surround themselves with people they trust, who can *go see* for them (Liker, 2004). Then, they *hou koku* (report), *ren-raku* (update) and *sou dan* (consult or discuss) what they have seen (Liker, 2004).

2.9.2 5 Whys

When involved personally through genchi genbutsu, problems are going to be identified. Then, the identified problem needs to be traced back to its root cause, which often is hidden beneath more obviously identified issues (Ohno, 1988; Womack, Jones & Roos, 1990). Toyota implements this by asking *why* five times to reach the root cause (Ohno, 1988; Womack, Jones & Roos, 1990; Shingo, 1984). Ohno (1988) exemplifies the process of *5 Whys* when confronted with a machine that has stopped:

- Why? A fuse blew due to an overload.
- Why? Not enough lubrication on the bearing.
- Why? The lubrication pump did not pump sufficiently.
- Why? Due to a shaft that was worn out.
- Why? Metal scrap was present because there was not a strainer attached.

In this example, the root cause is found within the machine, but Olhager (2013) emphasizes that it can often be found elsewhere in a complete different area from where the problem is identified.

2.9.3 5S

TPS goes beyond the production processes themselves and covers aspects of the entire organisation (Olhager, 2013). Therefore, Toyota has developed a method that creates and maintains a clean, efficient and organized work environment being the foundation for optimized processes (John, Meran, Roenpage & Staudter, 2008). The method consists of five words all starting with *S*:

- *Seiri – Sort*. Remove unnecessary equipment and tools from the working environment (Olhager, 2013).
- *Seiton – Set in order*. Every equipment or tool has there own spot (Olhager, 2013). Make sure everything is in place (Olhager, 2013).
- *Seiso – Shine*. Keep equipment and own workplace clean (Al-Aomar, 2008, Olhager, 2013).
- *Seiketsu – Standardize*. Document work method and strive for *"best practive"* (Al-Aomar, 2008). For example, a board with planned production and follow-up, signaling systems and color codes (Olhager, 2013)
- *Shitsuke – Sustain*. Maintain the other four aspects by continuously improving operating procedures and the workplace environment through a habitual behaviour (Liker, 2004). This aspect is the hardest to achieve (Liker, 2004), since it requires regular audits, proper training, education, a culture of continuos improvements (Olhager, 2013) and a commited management (Liker, 2004).

According to Al-Aomar (2011), *5S* is easy to implement and can often be a starting point for a company to facilitate for other Lean methods. In the everyday work, *5S* maintains *transparency*, providing for an efficient flow of activities (Al-Aomar, 2011). Olhager (2013) presents some examples of possible outcomes implementing *5S*: minimized transportion, maximized visibility, and clear, simple and flexible layouts.

2.9.4 Poka-yoke

If a method is foolproofed, Toyota calls it *Baka-yoke* (*baka* means fool and *yoke* means avoid) (Shingo, 1984). But since most people often make mistakes unintentionally, they refer to the method as *Poka-yoke* (*poka* means unintentionally) (Shingo, 1984). Basically, *poka-yoke* is a mistake-proofing method (Liker, 2004; Olhager, 2013), which means in-built solutions making it almost impossible to make recurring mistakes (Olhager, 2013).

Shingo (1984) distinguishes between two types of poka-yoke: *stopping the process* and *signaling an error*. They are used when encountered by different types of errors, as shown in the matrix in *Figure 2.7*.

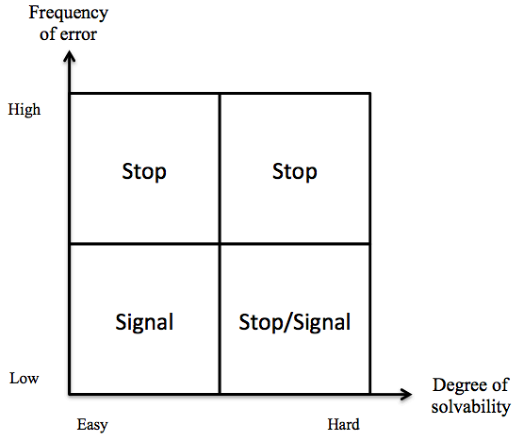


Figure 2.7. What type of poka-yoke method to use in regard to frequency of error and degree of solvability. Based on Shingo (1984), p. 33.

However, for both types of *Poka-yoke*, costs and risks need to be evaluated (Shingo, 1984). There is always a trade-off between costs of implementing poka-yoke methods and risks of deteriorating quality on a product.

2.9.5 Andon

When a machine halt, or there is a problem, some sort of signal is often used in TPS to indicate that help is needed for a quality problem to be solved (Liker, 2004). This can be lights, flags or even music or an alarm, and is referred to as *andon* (Liker, 2004). *Andon* originates from the Japanese lantern covered by paper to protect from the wind. *Andon* should be visible all over the production plant – from every workstation (Womack et al., 1990).

Important in TPS is to have a culture in which everyone takes responsibility for the quality (Olhager, 2013). When *andon* signals anywhere in the plant, any operator having a clue how to fix the problem runs there to help (Womack et al., 1990). The operators can, of course, also stop the production at once if needed (Olhager, 2013). Then, the problem needs to be taken care of immediately, because the production does not proceed before the problem is resolved (Olhager, 2013).

In old-fashioned mass production, to some extent managers often guarded information about a plant's condition (Womack et al., 1990). However, a Lean plant displays all information on the *andon* board, such as daily production targets, number of produced products that far, overtime requirements, equipment breakdowns, personnel shortages etc. (Womack et al., 1990).

2.10 Heijunka

Heijunka is part of the foundation of TPS/Lean, and is the Japanese word for *leveling*. The term refers to *volumes* and *mixes of items* being leveled out from day to day, so there is little variation in production (Liker, 2004; Olhager, 2013). Heijunka considers the total volume of orders over a period of time, and, then, produces the same amount and mix each day (Liker, 2004). Often, however, customer demand fluctuates from day to day (Liker, 2004), but this can be dealt with through *production leveling*, giving an even order flow to customers (Olhager, 2013). Moreover, collaboration with suppliers and customers are equally important, establishing, for example, standard times for delivery.

In the center of the TPS house one can find *muda* – the elimination of waste. However, it is equally important to minimize both *muri* and *mura*, which Toyota together with muda calls *the three M's* (Liker, 2004). Muri is overburden of equipment or people, which causes either breakdowns and defect or safety problems, while *mura* is unevenness in production (Liker, 2004). Many companies starting to apply Lean thinking often forget about muri and mura (Liker, 2004). Achieving heijunka is vital to reducing mura, which in turn reduces both muri and muda (Liker, 2004). The three M's fit together and affect each other.

When producing batches, the goal is to achieve economies of scale for each and every piece of an equipment (Liker, 2004). Then, it seems counter-intuitive to change tools to produce another product, both due to downtime between setups and salaries of personnel while setting up the machine (Liker, 2004). Therefore, many companies stick to large batches (Liker, 2004). Heijunka often requires a reduction of setup times (Yamashina, 1982; Liker, 2004), using for example SMED, and smaller batch sizes (Yamashina, 1982; Persson, 1996). Benefits, however, of leveling the schedule (heijunka) are:

- *Flexibility*. Producing what customers want when they want it reduces both *risk of unsold goods* and reduces *inventory* and correlated issues to a high inventory (Liker, 2004).
- *Predictability*. Heijunka creates a smoothed demand on processes upstream and, further, to suppliers (Liker, 2004).
- *Stability*. The use of labor and machines are balanced throughout the day, which make it easier to standardize work (Liker, 2004).

2.11 Standardized Work

Another foundation of TPS/Lean is to assure quality through standardized work (Olhager, 2013). This does not only mean standardizing *sequences of processes* and *sequences of how things are done*, but to standardize *takt time* and *stock on hand* (i.e. how much inventory does a worker need in a process) as well (Ohno, 1988; Persson, 1996; Liker, 2004). Standardization is the basis for *quality* and *continuous improvement* (Liker, 2004; Olhager 2013), since neither is it possible to improve processes without standardization, nor guarantee quality without standard procedures (Liker, 2004).

There are three elements to consider in the process of standardization according to Ohno (1988). The elements are *the machine*, *the material* and *the worker* (Ohno, 1988). Since *people involvement* is central in TPS/Lean, Ohno (1988) accentuates the combination of all elements. Otherwise, the operators will feel alienated not reaching optimal efficiency (Ohno, 1988). Therefore, Ohno (1988) also suggests that standards are set by the production workers themselves, rather than by management only. Thereafter, the operators are the ones who improve the standards (Liker, 2004).

2.12 Visual Management

In TPS/Lean, visual management is enforced everywhere (Ohno, 1988). This is implemented through *visual control*, i.e. methods showing the presence of abnormalities at one glance (Liker, 2004). Many methods already described in this chapter are visual control systems, such as *kanban*, *standardized work*, *5S*, *one-piece flow* and *andon* (Liker, 2004). However, Liker (2004) also emphasizes the importance of using visual management charts and graphs everywhere, showing the actual status of each area (Liker, 2004). This can be implemented through *process control boards*, i.e. white boards with important data (Liker, 2004). A simple process control board is pictured in *Figure 2.8*.

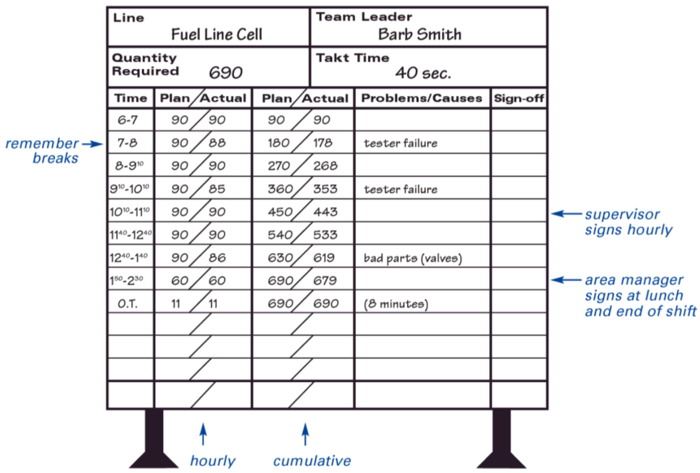


Figure 2.8. An example of a process control board. Retrieved from Rother and Harris (2001), p.86.

Another TPS/Lean method for visual management is through *A3 Reports*. A typical A3 report is a full report documenting a process with its, for example, *problems*, *current situation*, *root causes*, *alternative and recommended solutions* and *a cost-benefit analysis* – all on one sheet of paper (A3) to access key information (Liker, 2004). The aim of visual controls is to ensure that no problems are hidden, and designing a transparent environment without waste (Liker, 2004).

2.13 Process Mapping

Faced with global competition, companies are working hard to re-invent themselves (Davies, 1997). Twenty years ago, Davies (1997) reported that process orientation already did replace traditional functional or task orientation in businesses, which could be seen in world-class companies of that time. The trend holds for the business environment of today (see Assen, 2018; Miri-Lavassani & Movahedi, 2018; Novak & Janeš, 2019), in which Miri-Lavassani & Movahedi (2018) even see a relation between the degree of business process orientation and higher supply chain performances, such as, for example, direct effect on manufacturing lead time and product innovation through a higher level of process orientation in a core activity as production.

To boost efficiency in production, *processes* need to be top priority (Shingo, 1984). Shingo (1984) – the creator of *SMED* and progenitor of TPS/Lean – explains that it is vital to understand not only processing itself, but all parts of a process (i.e. processing, inspection, transportation and storing). Because, as W. Edwards Deming puts it, *"if you can't describe what you are doing as a process, you don't know what you're doing"* (Martin & Osterling, 2014, p. 15). That makes me think of the cult figure and Nobel prize laureate in physics 1922, by many considered a genius, Albert Einstein, who would have said that all physical theories should be described in such a simple way *"that even a child would understand"* (De Broglie, 1962). The trustworthiness of that statement can be argued, but the statement is, however, true for not only physical theories, but for logistics management, their processes and value streams also.

2.14 Visual Mapping Techniques

A first step to develop some sort of understanding of a company is by mapping the processes (Christopher, 2005). This is vital for finding opportunities of improvement in productivity later on (Christopher, 2005). However, there exist several *visual mapping techniques*, having different characteristics and objectives (Kalman, 2002). Therefore, it is essential to implement right tools to enhance positive results in operations (Ismael, Ghani, Ab Rhaman, Md Deros & Che Haron, 2013). Otherwise, in the end, the processes can end up even worse in terms of, for example, lead time, productivity and NVA activities (Ismael et al., 2013). Some of the many visual mapping techniques are briefly evaluated in this paper based on Kalman's (2002) comparison of *process mapping tools* and their *success factors.* Thereafter, a few are described in more detail.[5] *Figure 2.9–2.13* below illustrates a *block diagram,* a *cross-functional diagram*, a *decision (ANSI) flowchart*, a *quality process language diagram* and a *SIPOC diagram,* respectively.

[5] Visual mapping techniques used in this paper are described in more detail.

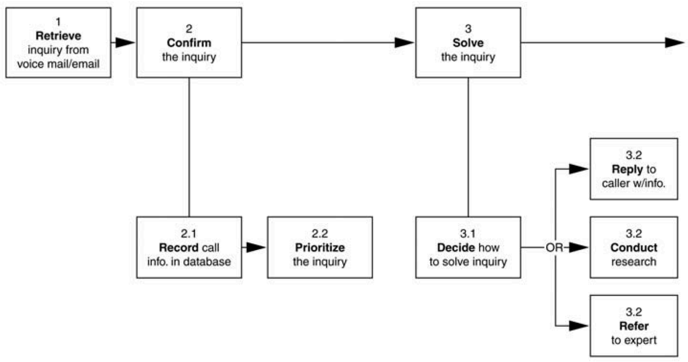


Figure 2.9. A block diagram, in which functions/processes are represented by blocks, and connected with lines to show interrelationsships. Retrieved from Kalman (2002), p. 64.

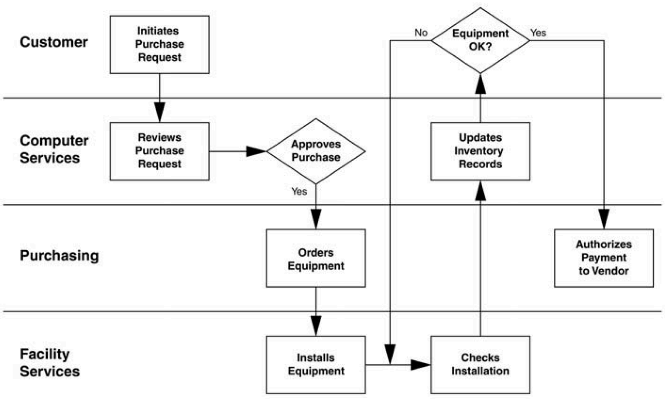


Figure 2.10. A cross-functional flowchart is organized into sections (swimlanes) showing responsibility over processes (blocks), decision-making (diamonds) etc. Retrieved from Kalman (2002), p.66.

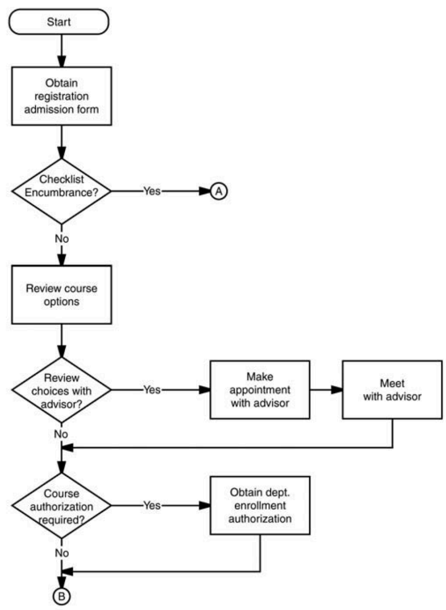


Figure 2.11. A decision (American National Standards Institue) flowchart, which focuses on decision-making. Retrieved from Kalman (2002), p. 65.

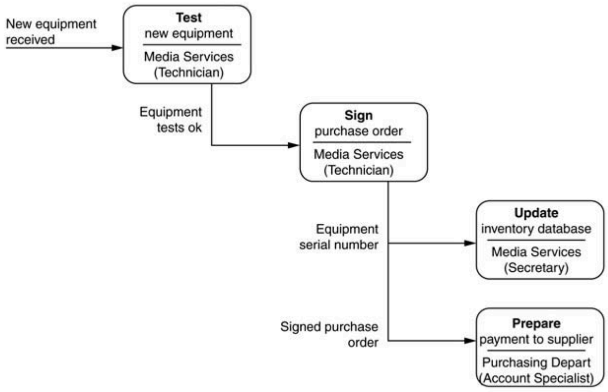


Figure 2.12. A quality process language diagram, illustrating inputs, outputs, processes and responsibility. Retrieved from Kalman (2002), p. 67.

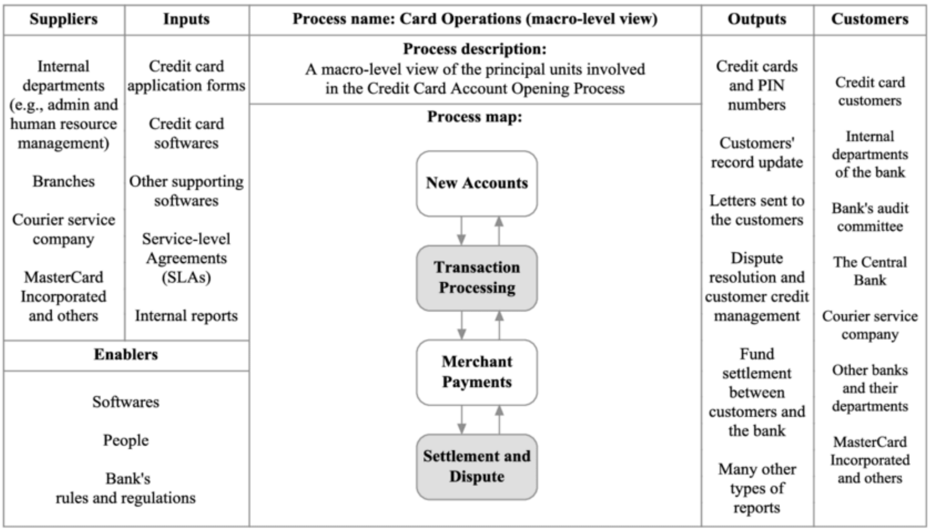


Figure 2.13. A Supplier, Input, Process, Output, Customer (SIPOC) diagram, illustrating different aspects around five areas of the supply chain. Retrieved from Islam (2016), p. 19.

Nine *visual mapping techniques* are evaluated briefly in this paper. The evaluation is based on four aspects with some relevant questions:

- *Perspective.* What type of level does the process mapping tool incorporate? Is it designed for *micro*- or *macro-level* events, and is it used for *operational*, *tactical* or *strategic* decision-making?
- *Characteristics.* What are the main charateristics as well as the aim of the technique?
- *Advantages.* What is the expected positive outcome using this technique?
- *Disadvantages.* What are the drawbacks of this technique?

A summary of the techniques can be seen in *Table 2.2*, which is primarily based on Kalman (2002).

Table 2.2. A summary of visual mapping techniques and their characteristics, primarily based on Kalman (2002).

Visual mapping technique	***Perspective***	***Characteristics***	***Advantages***	***Disadvantages***
Block diagram *(Figure 2.9)*	Quick, high-level overview of major process components. Strategic.	Focuses on a system's input and output, but less in-between.	Overall concept.	Can be too simple. Black box principle in-between input and output.
Cross-functional flowchart (Swim-lanes) *(Figure 2.10)*	In-between macro and micro level. Strategic.	Provides the relationship between functions and their responsibility of each step.	Indicates responsibility. Work against silo effects.	Difficult to use in complex systems.
Decision (ANSI) flowchart *(Figure 2.11)*	In-between macro and micro level. Strategic or operational level.	Evaluates consequences of particular decisions.	Documents simple systems. Facilitates operation decisions.	Unilateral.
Operation chart (Time and motion chart) *(Figure 2.18)*	Detailed but enhances strategic and tactical decisions.	Identifies VA and NVA activities.	Considers the entire process (i.e. processing, inspection, transportation and storage). Quantitative.	Time-consuming. Risk of getting too much into detail.
Quality process language diagram *(Figure 2.12)*	Micro-level. Strategic.	Identifies interactions between information and processes	Enhances quality. Visualizes responsibility.	Unstructured. Unilateral.
SIPOC *(Figure 2.13)*	Macro-level as basis for strategic decision-making.	Visualizes processes from beginning to end of the supply chain.	Includes the entire supply chain.	Lack of detail. Often presented in the end of a project.

Visual mapping technique	***Perspective***	***Characteristics***	***Advantages***	***Disadvantages***
String diagram (Geographical flowchart) *(Figure 2.19)*	Macro-level Operational understanding which enhances strategic decisions.	Identifies the physical flow in a system.	Identifies delays. Visualizes transports.	May be cluttered.
Value vs. time graph *(Figure 2.20)*	Macro-level. Strategic understanding.	Identifies how value increases over time.	Visualizes essential NV activities. Simple to use.	No process details.
Value stream mapping *(Figure 2.14)*	Macro-level for strategic improvements.	Identifies and removes waste.	Clearly visualizes the efficiency of production and bottlenecks. Information flow and material flow. Quantitative.	Does not incorporate transportation.

Olhager (2013) states that the *operation chart* and *geographical flowchart* together support for a good analysis of process flows. The operation chart is quite detailed including both time and transportation metrics, while the geographical flowchart illustrates the physical flow on a macro-level. In combination with *value stream mapping (VSM)* and *value vs. time diagram (VTD)*, they serve as a good process mapping framework. VSM is a proven Lean tool serving as the basis for Lean improvements, and VTD is a simple and time-effective method for visualizing the issues of NVA activities. All these *visual mapping techniques* focus on identifying and eliminating NVA activities, using different methods with diverse perspectives.

2.14.1 Value stream mapping (VSM)

According to Liker (2004), the first thing to do from a Lean perspective in a manufacturing company is to really understand the production. This is often done by mapping the value stream through VSM (Liker, 2004). VSM basically seeks to illustrate which production processes that *actually* add value to a product (Olhager, 2013).

A VSM, firstly, illustrates the *current value stream*. But the method also focuses on a *future state*, and tries to create an *ideal state* as well (Rother & Shook, 2001; Chen, Lee & Shady, 2010; Martin & Osterling, 2014; Yüksel & Uzunovic, 2019). A VSM often consists of an *information flow* at the top, *value-added processes* including basic data in the center and, most importantly, total lead and processing times at the bottom. This is illustrated in *Figure 2.14*.

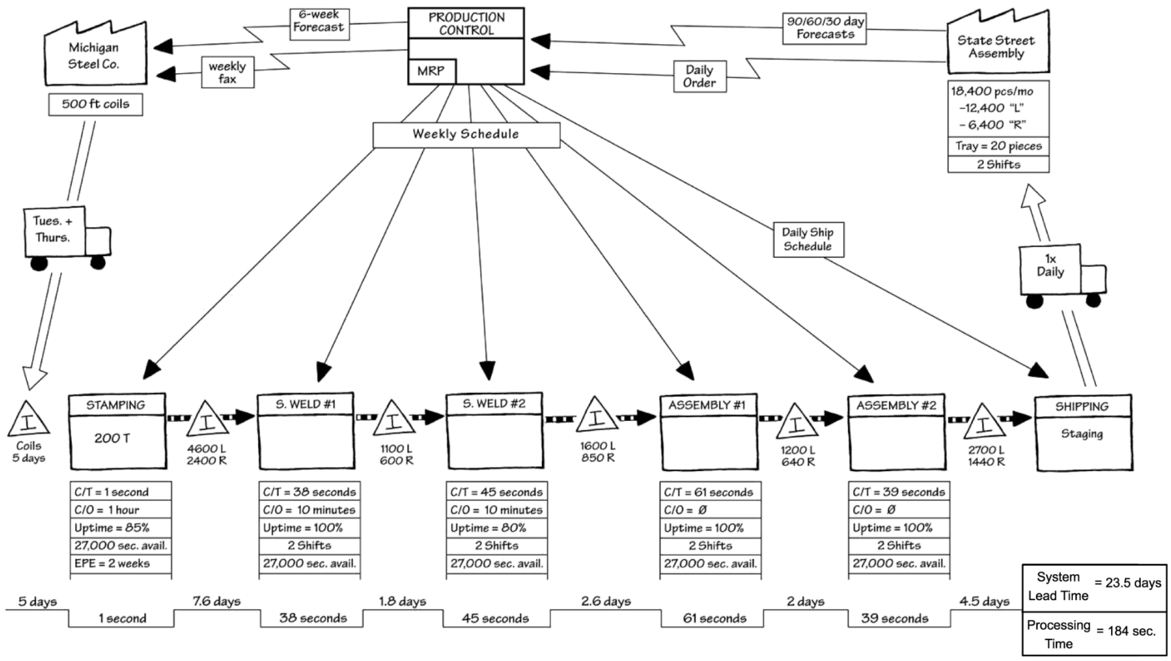


Figure 2.14. An example of value stream map. Retrieved from Rother and Shook (2001), pp. 28-29.

Mike Rother and John Shook introduced the method of VSM in *Learning to See* in 2001. Just like TPS and Lean, VSM has its origins in Toyota Motor Corporation, developed from a mapping technique called *mapping material and information flows* (Rother & Shook, 2001; Martin & Osterling, 2014).

2.14.1.1 Objective.

The final aim of applying VSM, basically, is to provide systematic workflow by eliminating NVA activities, i.e. waste (Rother & Shook, 2001). The method is a practical way of visualizing how work flows – or does not flow – through a corporation (Martin & Osterling, 2014), both regarding *material* and *information* (Rother & Shook, 2001). Meudt et al. (2017) emphasize that VSM is a proven tool for finding potentials of improvement. Over time, VSM has been accepted as one of the key instruments in Lean production due to its ability to transparently illustrate the as-is state of the processes and, then, address the impact of improvements (Yüksel & Uzunovic, 2019).

2.14.1.2 Advantages & Disadvantages.

Since VSM offers a holistic view of workflow, it is a tool for making strategic improvements (Martin & Osterling, 2014). Moreover, the benefis of using a VSM are that it (1) deepens the understanding of which processes actually bringing value to the customer, (2) provides highly visual maps of the entire flow, (3) uses quantitative measures helping strategic decisions and (4) focuses on cross-functional improvements rather than functional-based ones (Martin & Osterling, 2014).

In many organizations, a single person can often not – in any level of detail anyway – describe the entire process of transforming a customer order into finished goods (Martin & Osterling, 2014). This leads to silo effects, only to create problems somewhere else in the value stream. Often, it also leads to not solving root causes of problems, and can drive companies to implement expensive technologies that actually do little to address these root causes (Martin & Osterling, 2014). Not having a clear understanding of how workflow across a system often also result in poor business decisions, poor performance and poor work environments (Martin & Osterling, 2014).

2.14.1.3 Implementation of VSM.

Martin & Osterling (2014) describe a VSM as a five-phase process, pictured in *Figure 2.15*. There is a *preparation phase,* a phase of *understanding current state*, a phase of *designing future state* and, then, two phases including *developing* and *executing transformation plans.*[6]

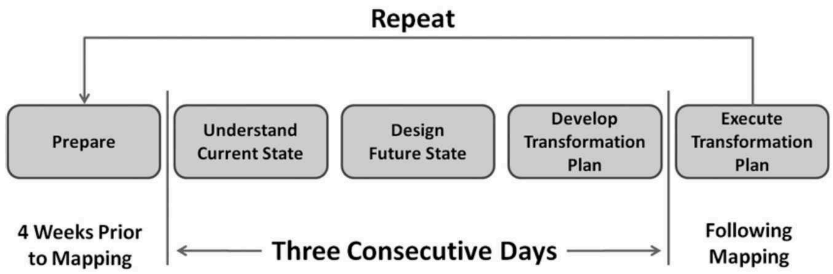


Figure 2.15. Value stream mapping phases. Retrieved from Martin and Osterling (2014).

2.14.1.4 Prepare.

According to Martin and Osterling (2014), preparation is the greatest *success factor* for a VSM process to become useful in the end. Therefore, a VSM charter should be developed for four main reasons: communication, planning, building consensus and aligning (Martin & Osterling, 2014). For example, information such as *scope, boundaries, current problems, drivers* and *accountable parties* can be part of the chart (Martin & Osterling, 2014).

2.14.1.5 Understanding current state.

Martin and Osterling (2014) recommend to start up with an activity kickoff to communicate the VSM charter and to dissolve a mindset of silo thinking. Then, at least three days on-site mapping work is suggested by several authors such as Martin and Osterling (2014), and Hines and Rich (1997).

Regardless of industry, the physical walk is a critical first step: the *gemba walk* (Martin & Osterling, 2014). Recently, gemba has become a popularized term (Liker, 2004). The term is closely related to genchi genbutsu, and refers to the *"actual place"* (Liker, 2004). It refers to the fact that the first thing to do in any problem-solving process is to understand the actual environment from first-hand experience (Liker, 2004).

In the process of understanding current state, Martin and Osterling (2014) suggest the three key metrics mostly used:

[6] Due to time limitations, this paper focuses on the first three steps only.

- *Process time (PT).* The completion time of the process of a part, basically, transforming an input to an output (Osterling & Martin, 2014).
- *Lead time (LT), (also called Throughput time).* The time it takes to make work available to a process until the work is available to the succeeding process (Osterling & Martin, 2014).
- *Per cent complete and accurate (%C&A).* This measurement refers to a process' *quality output* (Martin & Osterling, 2014).

A summary of the key metrics for the current state, and, after the following step, the projected future state. This type of summary is demonstrated in *Figure 2.16*. The *activity ratio (AR)* is the ratio between PT and LT (Olhager, 2013; Martin & Osterling, 2014). The AR is often not more than two to five per cent (Martin & Osterling, 2014). Stalk and Hout (1990) even coined the term "the 0.05 to 5 per cent rule", which emphasizes the wide spectrum of AR as well as the difficulty for a manufacturing company to exceed five per cent (Olhager, 2013). Moreover, *rolled %C&A* is a multiplication of each process' *%C&A*.

Metric	Current State	Projected Future State	Projected % Improvement
Total Lead Time	9.5 days	3.5 days	63.2%
Total Process Time	180 minutes	160 minutes	11.1%
Activity Ratio	3.9%	9.5%	143.6%
Rolled % Complete & Accurate	30.0%	89.3%	197.7%
Other			
Other			

Figure 2.16. An example of a summary of value stream key metrics. Retrieved from Martin and Osterling (2014).

2.14.1.6 Designing future state.

Relevant countermeasures, which have been introduced through the entire *theoretical framework* of this paper, are taken into consideration while designing future state. Only getting the basics in place, such as visual managament, standardized work and build-in quality, often leads to major reductions in lead time (75 per cent), process time (25 per cent) and quality improvements (Martin & Osterling, 2014). But to establish this, key performance indicators (KPI) are necessary. KPIs are what reflect value stream performances on a micro-level (Martin & Osterling, 2014). Every value stream needs two to five KPIs, whether they are measurements for time, safety, morale, quality, cost or anything else. (Martin & Osterling, 2014).

Finally, a *Prioritization, Action, Consider, Eliminate (PACE) chart* is established to increase the ease of decision-making, especially if there is a time contraint on the implementation process (Martin & Osterling, 2014). A PACE chart is illustrated in *Figure 2.17*.

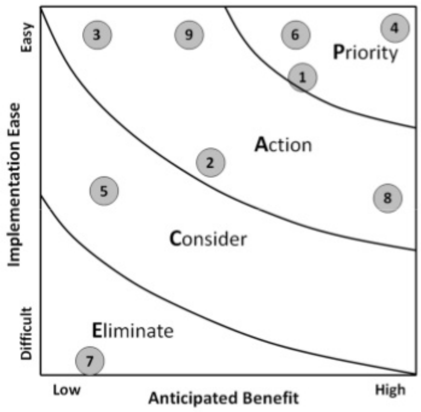
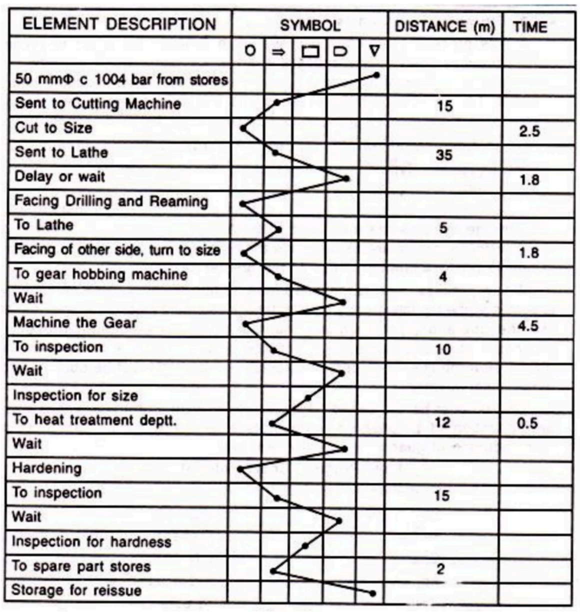


Figure 2.17. PACE chart. Retrieved from Martin and Osterling (2014).

2.14.2 Operation chart (also Time and motion chart)

In an operation chart, the entire work sequence of a batch of a specific product is analyzed (Olhager, 2013). There are several types of operation charts presented in the literature (see e.g. Shingo, 1984; Olhager, 2013), but one is illustrated in *Figure 2.18*. Every process contributes to the chart with a measure in either time or distance (one of them is negligible). Each process is also, often, divided into a value code consisting of VA, NVA and ENVA activities. Furthermore, each process is divided into one of the following categories of activities:

- *Processing.* A process that transforms an input (e.g. raw material or semi-manufactured goods) closer to finished goods.
- *Transportation.* The part is moved between different places.
- *Inspection.* An inspection examines and verifies the result of another process (Olhager, 2013). Does the part, for example, meet the established standard in quantity and quality?
- *Storing.* The part is waiting for another process, or to be delivered to customer.



ELEMENT DESCRIPTION	SYMBOL					DISTANCE (m)	TIME
	O	⇒	☐	D	∇		
50 mmΦ c 1004 bar from stores							
Sent to Cutting Machine						15	
Cut to Size							2.5
Sent to Lathe						35	
Delay or wait							1.8
Facing Drilling and Reaming							
To Lathe						5	
Facing of other side, turn to size							1.8
To gear hobbing machine						4	
Wait							
Machine the Gear							4.5
To inspection						10	
Wait							
Inspection for size							
To heat treatment deptt.						12	0.5
Wait							
Hardening							
To inspection						15	
Wait							
Inspection for hardness							
To spare part stores						2	
Storage for reissue							

Figure 2.18. A operation chart. Retrieved from Chand (2015).

2.14.3 String diagram (also Geographical flowchart or Spaghetti diagram)

A *String diagram* illustrates the physical flow of work activities (Kalman, 2002). The activities illustrated in the operation chart are basically transfered onto the production facility layout (Olhager, 2013). Most importantly, string diagrams clarify how products are transported between processes (Olhager, 2013). Such a diagram, also called spaghetti diagram, is illustrated in *Figure 2.19* below.

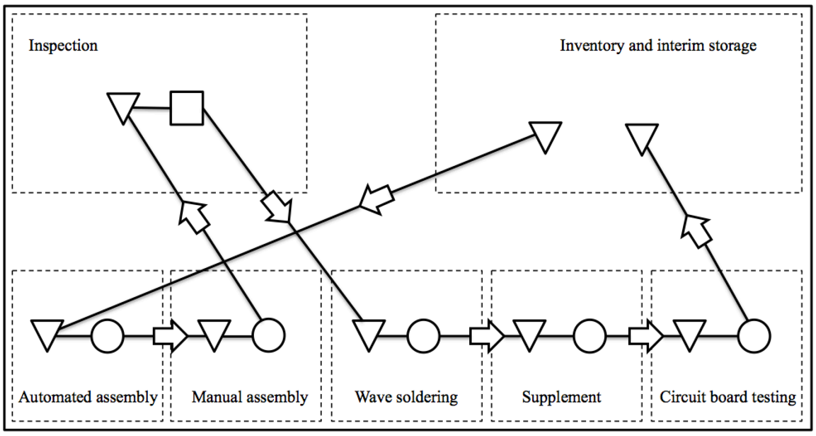


Figure 2.19. A spaghetti diagram from the electronics business in manufacturing circuit boards. Retrieved and translated from Olhager (2013), p. 141.

2.14.4 Value vs. time graph (VTG)

The VTG is a roughly visualization tool that highlights the time spent on VA activities and NVA activities, respectively (Christopher, 2005). The tool is similar to value stream mapping, but is simpler and also shows how value increases within the company in terms of tied-up capital. The VTG can be seen in *Figure 2.20*. The aim is, of course, to reduce NVA activities by compressing the graph to the left (Christopher, 2005). Since tied-up capital can be seen as the area below the graph, a company should strive for compressing the *cost-adding time* later on in the value stream.

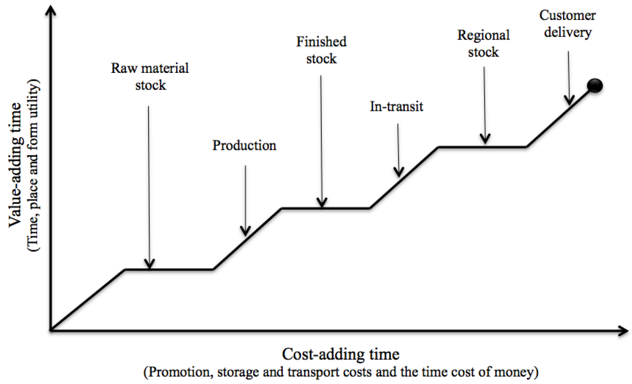


Figure 2.20. A value vs. time graph. Retrieved from Christopher (2005), p. 158.

2.15 Product Family Matrix

Many companies assume their layout needs to be arranged as a *job shop layout*, i.e. same type of operations and equipment at the same place (Hall, 1987). Surely, there are benefits with a job shop layout, such as *physical restrictions* (e.g. dirt, contamination, noise, location of tools etc.) and *operational restrictions* (e.g. people with similar skills are close to each other) (Hall, 1987). There can be difficult to break down a system that probably is built by individual specialists in each department (Hall, 1987), which contributes to silo effects.

However, it is important to try to re-arrange the work sequence in various ways to design a layout enhancing production flow (Ohno, 1988). Changing the layout often increases flexibility, eliminates waste and contributes to JIT (Hall, 1987). One way is to strive for *cellular manufacturing*. The operations are, then, arranged close to each other, often in a U-shape (Hall, 1987). This shortens lead times through the production, visibility, and decrese overall costs, distances and floor space (Hall, 1987). Finally, Hall (1987) emphasizes that the entire plant should be thought of as a cell to enhance overall efficiency even further.

A start of implemementing a change in layout is often through the *product family matrix*, illustrated in *Figure 2.21*. A product family is a group of products flowing through similar processes and machines downstreams (Rother & Shook, 2001). However, Rother and Shook (2001) emphazise the importance of not performing a mapping of all products manufactured by the company, but a selection of products due to complexity. *Value to customer* is the starting point while identifying product families (Rother & Shook, 2001).

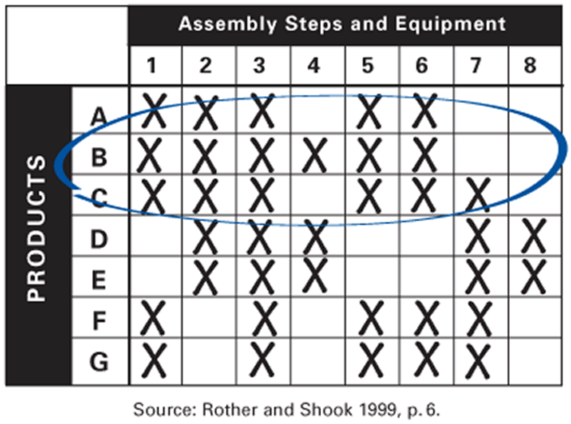


Figure 2.21. A product family matrix with products on the y-axis and assembly steps and equipment on the x-axis. Retrived from Rother and Shook (2001), p. 4.

2.16 Ishikawa Diagram

Ishikawa diagram, also known as *fishbone diagram* or *causes and effect diagram*, is an analysis method for problems that have been found (Schonberger, 1983). Identified problems are often an effect of other problems, and hence it is important to find the root causes (Olhager, 2013). In that sense, the method is similar to *5 Whys* (Olhager, 2013).

The problem is written to the right, but there is at least two types of methods used. Schonberger (1983) suggests that causes having greatest impact on the problem are written on the mainlines of the fishbone. Olhager (2013) with many other authors, however, suggests splitting the main lines into six M's: *man, material, measurement, method, machine* and *mother nature (environment)*. Sectioning like this helps to structure the approach of the problem at hand (Olhager, 2013). An example of such a structure can be seen in *Figure 2.22*.

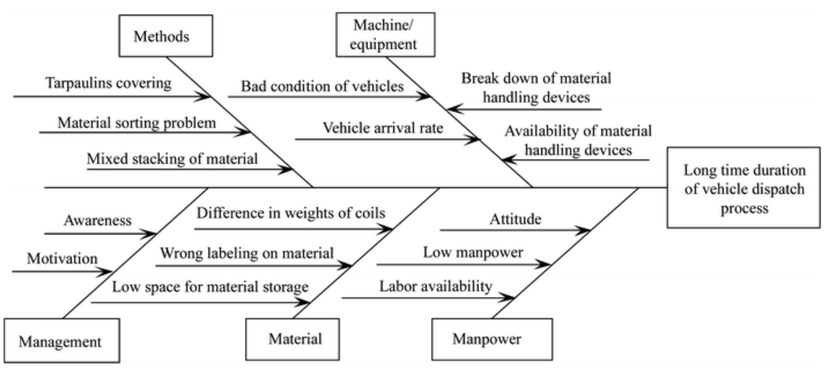


Figure 2.22. An example of a Ishikawa diagram. Retrieved from Zuting, Mohapatra, Daultani and Tiwari (2014), pp. 333-343.

2.17 Plan-Do-Check-Act (PDCA)

The PDCA cycle is a structured approach for solving *quality problems* and achieving *quality improvements* (Olhager, 2013). The method is a corner stone of continuous improvement (Liker, 2004), since it is an everlasting process (Olhager, 2013) as can be seen in *Figure 2.23*.

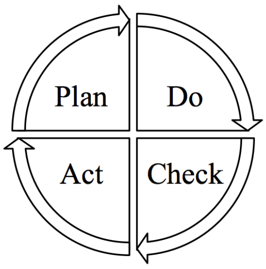


Figure 2.23. The plan-do-check-act cycle.

- *Plan.* Define and understand the gap between current and future states, for instance through *genchi genbutsu* (Olhager, 2013). Root causes can, then, be analyzed by implementing the *Ishikawa diagram* (Olhager, 2013).
- *Do.* Test improvement solutions on small-scale (Olhager, 2013).
- *Check.* Assess the results of the pilot study (Olhager, 2013).
- *Act.* Implement a standardized work method to avoid the problem to arise in the long-term by solving the root cause (Olhager, 2013).

2.18 Process Capacity and Bottleneck Elimination

Capacity is the workload a resource in production can perform over a given period of time (Olhager, 2013). How much capacity a company needs is mainly based on the demand (Olhager, 2013). Capacity utilization of a resource can be calculated by applying *Equation 1* below:

$$U_j = \frac{\sum_{i \in j} D_i \, t_{ij} + \frac{D_i}{Q_i} s_{ij}}{CAP_j} \tag{1}$$

where U_j = capacity of resource j
D_i = demand of product i (pcs per time unit)
Q_i = batch size for product i (pcs)
t_{ij} = processing time for product i in resource j (time units per piece)
s_{ij} = setup time for product i in resource j (time units)

CAP_j = capacity in resource j (time units per time unit)

Both Mattsson and Jonsson (2003) and Olhager (2013) suggest some methods for balancing the *available capacity* (denominator in *Equation 1*), such as (1) investing in new machines, (2) hire or dismiss personnel, (3) change number of shifts and (4) put in overtime. On the other hand, there is *capacity requirement* (numerator in *Equation 1*), which is the planned workload and consists of two parts: processing time and setup time (Olhager, 2013). There are other methods to balance the capacity requirements. Mattsson and Jonsson (2003) and Olhager (2013) state some methods for changing capacity requirement, such as:

- *Balancing batch sizes.* Minimizing batch sizes, for example, increases the number of setups, which leads to increased capacity requirement (Olhager, 2013).
- *Reduce setup times.* A setup time reduction enables a reduction in batch size. For example, a 50 per cent reduction in setup times enable a 30 per cent reduction in batch sizes based on the economic order quantity (EOQ) formula (Olhager, 2013).
- *Sub-contracting*, to minimize a company's capacity requirement (Olhager, 2013).
- *Redistribution of capacity requirements.* Basically, moving workload between resources (Olhager, 2013), which is illustrated in *Figure 2.24* below.

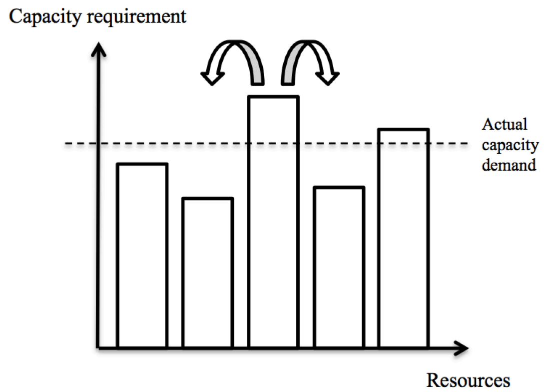


Figure 2.24. A capacity requirement analysis, showing the balancing of capacity. Based on Persson (1995) and Mattsson and Jonsson (2003).

Anything, but often a machine, that restricts the capacity of a system is a *bottleneck* (Olhager, 2013). If the bottleneck is a machine, it is essential to maximize its utilization since it is the controlling resource (Olhager, 2013). Olhager (2013) supports the idea of having the bottleneck early on in the system, since this creates *flow* through the system due to overcapacity in succeeding resources. Olhager (2013) also presents a model for bottleneck elimination, which includes following steps:

1. Identify the bottleneck.
2. Decide how the bottleneck should be utlized.
3. Subordinate everything to this decision.
4. Increase the capacity of the bottleneck.
5. If a bottleneck is eliminated, start over.

2.19 Flow Efficiency

Lean can also be described by differentiating between two types of efficiencies (Modig & Åhlström, 2012): *(1) resource efficiency* and *(2) flow efficiency*. Resource efficiency measures the utilization of resources, and focuses on increasing the time an equipment, machine or tool is used (Modig & Åhlström, 2012). This is often – and has been since the industrial revolution – the natural way of looking at efficiency (Modig & Åhlström, 2012). Flow efficiency focuses on the entity that flows through the system (Modig & Åhlström, 2012). Flow efficiency, basically, is a measure of how fast a customer order is fulfilled.

A company needs to strive for both of these efficiencies to increase profitability and customer satisfaction, and becoming *lean* (Modig & Åhlström, 2012). Modig and Åhlström (2012) illustrate the efficiencies in a framework called *the efficiency matrix*. The efficiency matrix, which is pictured in *Figure 2.25*, suggests that a company can be in one out of four states:

- *Efficient islands,* meaning that an organisation consists of suboptimal areas, which maximize their *resource efficiency* regardless the flow outside of the department (Modig & Åhlström, 2012). This is often illustrated by products spending a lot of time in inventory (Modig & Åhlström, 2012).
- *Efficient ocean* is the other extreme of the matrix. To maximize *flow efficiency*, a company needs to release capacity from the resources, which means that resources is utilized only when their is an actual demand (Modig & Åhlström, 2012).
- *Wasteland*. A company neither managing to utilize their resources efficiently nor creating an efficient flow.
- *Lean (The perfect state)*. Organisations become *lean* when they have both high resource efficiency and high flow efficiency. However, it is hard to reach the perfect state, which is illustrated as a star in *Figure 2.25*, mostly due to *variation in demand* and *variation in supply*.

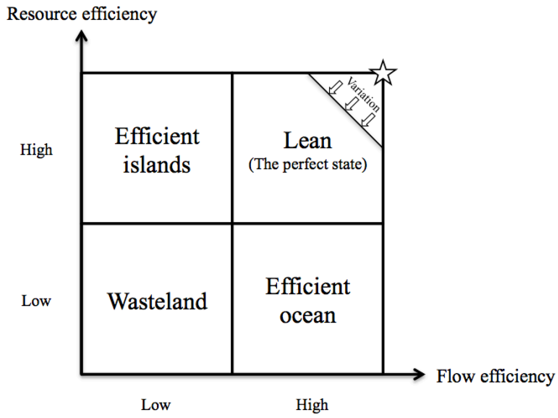


Figure 2.25. The efficiency matrix. Retrieved from Modig and Åhlström (2012), pp. 98.

Many organisations focus on *resource efficiency* over *flow efficiency,* which is counterproductive since it tends to increase superfluous work (Modig & Åhlström, 2012). For example, it brings longer lead times, which in turn adds secondary needs such as more inventory, more transportation, more administration, hidden problems etc. (Modig & Åhlström, 2012). By focusing on *flow efficiency*, organizations can reduce superfluous work and eliminate waste, and, further, become *lean*.

2.20 Lean Implementation

Both Liker (2008) and Womack et al. (1990) are authors who have dedicated plenty of years to the principles of Lean, and are, therefore, experts in the field. But are they biased in praising these principles like no others existed? In other words, why have not all companies followed the suggestion stated by Womack et al. (1990) to implement Lean?

Pech & Vaněček (2018) investigate the use of Lean production methods in 90 industrial enterprises[7] in different sizes and from different industries. Few companies having less than 249 employees were using Lean methods, but there is a trend that larger companies implement Lean methods to a higher extent (Pech & Vaněček, 2018). For example, almost 47 per cent of them are using *kanban*, around 23 per cent are using *JIT*, around 47 per cent are using *5S* and around 44 per cent are using VSM (Pech & Vaněček, 2018).

[7] The methodology for choosing the enterprises is not explicit in the publication; however, it is assumed that they are chosen based on availability and randomness.

2.20.1 Critical success factors (CSFs)

Ivarsson, Molin, Lashajko, Wiestål and Johnsson (2018) conducted a study based on 50 companies[8], also from different industries and of various sizes, operating in Sweden, to understand critical success factors (CSFs) of Lean. A conclusion from the study, and possibly an answer to Womack et al. (1990), is that Lean takes time to implement (Ivarsson et al., 2018). For example, companies that have applied Lean principles for more than three years are more successful than others (Ivarsson et al., 2018).

Moreover, a company benefits from implementing the whole concept of TPS/Lean. However, a study presented by Chauhan and Chauhan (2019) suggests that a phase-wise implementation approach shall be used in any manufacturing company due to (1) cost, resource and time restraints in implementing tools in tandem, (2) possibilites to correct through feedback from previous implementation problems and (3) motivation to continue implementing. The study also suggests to start implementing ”softer” tools, such as (1) developing mutual faith, (2) maintaining discipline, (3) delegate responsibility, (4) get employees to participate etc., while the most important factors are (1) elimination of waste, followed by both (2) just-in-time and (3) continuous improvement (Chauhan and Chauhan (2019).

Other CSFs in a Lean implementation are more related to how an organization approaches the change effort, rather than the use of specific methods (Näslund, 2013). Management support and organizational culture are often seen as especially critical (Näslund, 2013). Näslund (2013) presents three additional CSFs in (1) strategically aligning the initiative to the organization’s objective, (2) enhancing project management, since almost every change effort is project driven and (3) increased training due to the organizational change needed to implement Lean. Näslund (2013) states that if companies are informed of CSFs of a Lean implementation, the awareness can guide the companies to a successful implementation.

2.20.2 Maturity models

Maturity models are used as holistical assessment tools to capture a company’s current situation to support change (Maier, Moultrie & Clarkson, 2012). Generally, the models are conceptual frameworks consisting of steps describing the development of an area of interest (Pigosso et al., 2013). Any maturity model normally consists of four to six sequential steps building on each other (Pigosso et al., 2013). Such a model helps an organization to assess strengths and weaknesses of their business (Pigosso et al., 2013; Albliwi, 2017), as well as guiding them through the evolution

[8] A selection from goods and service organizations from both private and public sectors in Sweden (Ivarsson et al., 2018).

of an organizational change (Šajeva, 2009). It also allows for comparisons of similar efforts between departments, but more importantly, between companies (Šajeva, 2009).

The applications of maturity models are widespread among different areas (Pigosso, 2013). Röglinger, Poppelbuß and Becker (2012) even state that the number of maturity models is so high today that the practitioners and scholars might soon lose track. Therefore, only a few maturity models related to Lean implementations are evaluated further in this paper. The Lean maturity models are summarized in *Table 2.3*. The models are compared based on three aspects: Lean maturity levels, criteria and objective.

Lean maturity levels account for every step that a company can reach in the model, while *criteria* is the foundation of how the evaluation of a company's Lean maturity is done. The *objective* of a model can be either on a micro- or macro-level, focusing on either a single manufacturing cell or the entire organization.

Table 2.3. Comparison between different Lean maturity models (including this paper's model).

Author(s)	***Lean maturity levels***	***Criteria***	***Objective***
Albliwi (2017)	*Level 0: Uncertainty* (unsure about the Lean concept) *Level 1: Awareness* (trying basic ideas of Lean) *Level 2: Enlightenment* (more strategic Lean deployment) *Level 3: Capability* (strategic and planned Lean deployment with evident benefits) *Level 4: Certainty* (Lean deployment is not only a method but a belief) *Level 5: World-class* (Lean deployment in their DNA, with 15 years of CI)	1. Infrastructure and training 2. Top management commitment and leadership 3. Strategic alignment 4. Project selection and prioritization 5. Tools and techniques 6. Motivation and recognition 7. Financial benefits (ROI)	Macro-level assessment (both a score for each criteria and an accumulated score) of the entire organization.
Maasouman and Demirli (2016)	*Level 1: Understanding* (deploying Lean for standardization) *Level 2: Implementation* (deploying Lean effectively) *Level 3: Improvement* (deploying Lean efficiently) *Level 4: Sustainability* (deploying Lean with continuous daily excellence)	1. People 2. Facilities 3. Working condition 4. Production process 5. Quality 6. JIT 7. Leadership	Micro-level assessment (a score for each criteria and an accumulated score) of a manufacturing cell at the shop-floor.
Rampasso, Anholon, Silva, Ordóñez and Quelhaz (2019)	*Level 1* (little or no attention to Lean) *Level 2* (Lean is considered, but informal and irregular) *Level 3* (Lean is applied systematically in different degrees) *Level 4* (Lean is applied systematically and positive results are apparent) *Level 5* (Lean is in full use and essential for excellence)	1. Employee knowledge and skills 2. Quality and continuous improvement 3. Cell configuration 4. Leadership, autonomy and communication	Micro-level assessment (an accumulated score) of a manufacturing cell at the shop-floor.
Santos Bento and Tontini (2018)	*Level 1: Not implemented* *Level 2: Formally implemented* *Level 3: Deployed and documented with occational failures* *Level 4: Implemented and documented with indicators under control* *Level 5: Implemented, controlled, and continuosly improving* (last 12 months)	1. Strategic planning 2. Quality at source 3. Processes and tools 4. Problem solving 5. People 6. Supplier integration 7. Continuous improvement 8. Customer focus	Macro-level assessment (a score for each criteria) of the entire organization.
Uriarte, Ng, Moris and Jägstam (2017)	*Level 1: None* (starting point or no use of Lean) *Level 2: Partial* (individual application of a Lean process, but not repeatable and strategic) *Level 3: Formal* (well-performed and repeatable, but not fully integrated in the organization) *Level 4: Culturally embedded* (fully integrated in culture organization wide and repeatable)	1. Existing knowledge 2. Implementation of tools 3. Sustainability of implementation 4. Cultural impact	Macro-level assessment (an accumulated score) of the entire organization.
This paper's maturity model	*Level 0: Non-existing* *Level 1: Initial* (Lean principle is not fully implemented or in an early stage) *Level 2: Defined* (Lean principle is partly applied but lack in results; imp. for less than 1 year) *Level 3: Established* (Lean principle is applied in a structured way and positive results are apparent; imp. for less than 3 years) *Level 4: Excellent* (Lean principle contributes to overall success; imp. for more than 3 years) *Level 5: Textbook case* (Lean principle matches theory perfectly; imp. for more than 5 years)	1. Jidoka 2. JIT 3. People and teamwork 4. Heijunka 5. Standardized work 6. Visual management 7. Kaizen 8. Other Lean tools	Macro-level assessment (a score for each criteria) of the entire organization.

The Lean maturity models compared in *Table 2.3* above all have different *Lean maturity levels* based on different *criteria*. However, the maturity levels are influenced of the fact that a model's main objective is to generate an accumulated Lean maturity score based on all criteria. The objective may be a score for either the entire organization or a single manufacturing cell, but always accounting for all criteria. Moreover, the criteria of each model differ. The main differences, however, are in wording rather than meaning. All of the models incorporate aspects such as *people, quality, continuous improvement, tools* and to some extent *leadership, management* or *culture.* Finally, none of the models have on every maturity level incorporated the time aspects related to a Lean implementation.

The Lean maturity model presented in this paper builds on the comparison from *Table 2.3*. This paper's maturity levels are similar to many of the previous models, even though the maturity levels of this paper can be used for each criterion rather than as an accumulated Lean maturity score. The time aspect, based on Ivarsson et al. (2018), sparsely applied in other models, also influences the maturity levels in this paper. This model's criteria are based on the TPS/Lean house, but does incorporate many of the other models' criteria, such as *people* and *culture* (see *people and teamwork*), *quality* (see *jidoka*), *continuous improvement* (see *kaizen*) etc. The main objective of this paper's Lean maturity model differs from many of the other models in its goal of generating implementation scores for each criterion rather than an accumulated score. Each score can then be compared among companies to understand differences in more detail. This paper's Lean maturity model is pictured in *Figure 2.26*, and consists of the following stages: (0) non-existing, (1) intital, (2) defined, (3) established, (4) excellent and (5) textbook case.

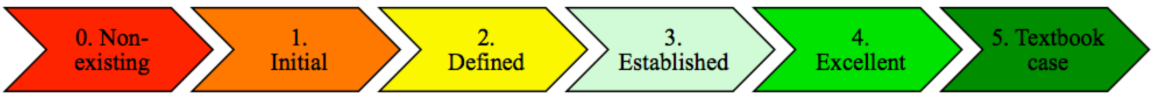


Figure 2.26. Maturity model for cross-case companies.

Each step of this paper's maturity model account for (1) degree of implementation of a specific criterion, (2) the time a specific criterion has been implemented within a company and (3) the knowledge about the criterion among personnel. Each step is described in more detail below:

- *Non-existing.* There is no implementation of this principle/method at the case company.
- *Initial.* The case company has not a structured way of using the principle, but at least awareness has been raised regarding how an implementation can be beneficial to the company. However, there are still uncertainties or a clear plan. Regarding time aspects, the

principle is in the early stages of implementation or in the conceptualization phase. There is seldom any knowledge about the principle around the company.

- *Defined.* The case company has a structured way of using the principle, but lack in the principle delivering the intended positive result. The principle has not been implemented for more than one year. There is no widespread knowledge about the principle around the company.
- *Established.* The case company has a structured way of using the principle in a sustained way, and the principle delivers intended positive results. The principle has been implemented for more than three year. There is a widespread knowledge about the principle around the company.
- *Excellent.* The principle contributes to the overall success of the company. The principle has been implemented in a successful way over a period of more than three years. There is a widespread knowledge about the principle at different operational levels around the company.
- *Textbook case.* The implementation of the principle is a textbook case, i.e. the use of the principle matches theory perfectly. The case company's application of the principle is seen as a "best-practice" case in their business. The principle has been implemented for more than five years, and everybody in the organization has knowledge about it.

Chapter 3. Methodology and Approach

This chapter outlines the methodological approach used in the research of this paper. In more detail, this chapter describes the approach, purpose, method and process of the research. It also elaborate on how data is collected and analyzed, as well as how high quality is attained in the process of conducting the research.

3.1 Overall Research Approach

Research consistently starts with a problem at hand, from which there is an interest of acquiring new or in-depth knowledge (Patel and Davidson, 2011). There is a distinction, however, between research and inquiry, where the former has a deeper theoretical foundation (Patel & Davidson, 2011). Despite this distinction, both produce knowledge for either *decision-making*, *educational purposes* or for being *basis of new knowledge* (Patel & Davidson, 2011). Thus, research uses a systematic approach to understand problems through scientific theories and research methods (Flick, 2015). The research, in turn, can be either *basic* or *applied* (Hedrick, Bickman & Rog, 2011; Patel & Davidson, 2011). This paper uses an applied theory for solving specific problems. In other words, a scientific methodology is used to produce knowledge from a social problem (Hedrick et al., 2011) through normative applications (Kasanen, Lukka & Siitonen, 1993).

The main objective of this paper is to recommend the principal company (TePe) on how to improve the materials flow to assembly lines within their production facility, based on four research questions. Therefore, the *constructive approach* suits this paper, since such a methodology includes *"problem solving through the construction of models, diagrams, plans, organizations etc."* (Kasanen et al., 1993, p. 243). Construction, here, refers to entities that produce solutions to explicit problems and create new realities (Kasanen et al., 1993). But more importantly, their usability can be demonstrated by an implementation (Kasanaen et al., 1993). Kasanen et al. (1993) have observed this type of approach being useful in many other Master's theses, and in operations research as well.

Logistics research is primarily based on a positivistic paradigm (Mentzer & Kahn, 1995; Näslund, 2002). Näslund (2002) describes *positivism* as the belief of an "objective" world, with "objective" methods to study it. Since the constructive approach is seen as part of the *systems approach* (Arbnor & Bjerke, 2009), it is as Gammelgaard (2003) puts it: *"pragmatic in nature"* (p. 481). Instead of searching for an absolut truth, there is a search for a problem solution working in practice (Gammelgaard, 2003). The systems approach is based on systems theory and is often seen as holistic in contrast to the usual atomistic approach of positivism (Gammelgaard, 2003).

Therefore, it suits the logistics field (Gammelgaard, 2003). The aim is to identify the systems parts, links and feedback mechanisms to be able to improve it (Gammelgaard, 2003).

3.2 Research Approach

The constructive approach is of normative, and mostly empirical, design (Kasanen et al., 1993). The importance of tying the problems and their solutions with accumulated theoretical knowledge cannot be overstated (Kasanen et al., 1993). *Figure 3.1* presents the approach used in this paper, and as can be seen, the solution needs *practical relevance* as well as *theory connection*. The construction should also be *practically functioning*, and it is beneficial if it provides theoretical contribution. In this paper, thus, there is crucial to link *TPS/Lean principles* with the practical challenges at the principal company.

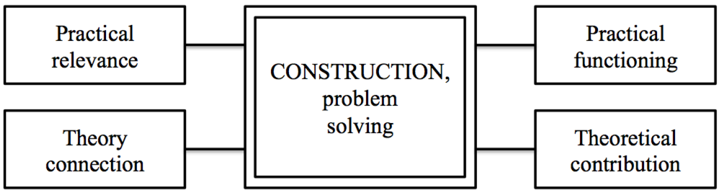


Figure 3.1. Elements of constructive research. Retrieved from Kasanen et al. (1993).

Based on these elements, Kasanen et al. (1993) arrange the research process of a constructive approach into six generic phases. These phases are used as the foundation of this paper, and links the construction to the four elements illustrated in *Figure 3.1* above.

1. *Find a problem that is relevant, practical and potentially research-friendly* (see Kasanen et al., 1993; Patel & Davidson, 2011). For this paper, the principal company suggests a few problem areas, which are discussed before arriving at initial research questions.
2. *Acquire a comprehensive understanding of the topic.* An extensive literature framework has been applied onto this paper, since step three *(construct possible solutions)* is central for the constructive approach to be successful (Kasanen et al. (1993). Without the right amount of knowledge, there is a wild goose chase for, at least any good, solutions.

   Besides, a literature review is conducted to guide the researcher into this comprehensive understanding of the *right* literature. This, in turn, contributes to evidence-based practice. Because if the researcher does not come up with any ideas, there is, quite frankly, no use in progressing the research (Kasanen et al., 1993). In this phase, the research questions are permanently set.

3. *Construct possible solutions.* This phase is the *core element* of a successfully applied constructive approach (Kasanen et al., 1993). This paper is partly characterised by heuristic innovations (Kasanen et al., 1993), since *direct observations* and *interviews* are the basis from where solutions for the *materials supply* are constructed.
4. *Demonstrate that the solutions work.* This paper follows the constructive research approach of always explicitly demonstrate constructed solutions' practical usability (Kasanen et al., 1993). In this paper, workshops with key employees are held to increase validity and establish the solutions. This is important to reinforce the elements of practical relevance and practical functioning. *Workshop I* is mainly held to evaluate the progression of solutions thus far, and to understand critical success factors of further development. *Workshop II* is the final evaluation by key employees, which assess the practical functioning of the solutions through an evaluation sheet. Practical information about how *Workshop I* and *Workshop II* is conducted can be found in *Appendix I* and *Appendix II*.
5. *Show theoretical connections and how the solutions contribute to research.* This paper aims on not only finding relevant solutions, but contributing to academic research with yet another application of the contructive research approach, but on *materials supply processes* in a manufacturing firm.
6. *Examine solutions' scope of applicability.* Kasanen et al. (1993) emphasize the likeliness of the solution being applicable in similar firms if it suits the principal company. The constructions are, therefore, linked to previous case research studies to confirm applicability.

3.3 Research Purpose

Research is a rigorous and intricate process (Mentzer & Kahn, 1995). However, logistics research is still maturing, not offering many well structured research processes (see Mentzer & Kahn, 1995; Eisenhardt, 1989; Näslund, 2002). Therefore, planning is crucial in this logistics Master's thesis to ensure that a rigorous methodological procedure is followed (Yin, 2014). The first step in this process is the development of sharp and answerable research questions (RQs), which builds a foundation of the paper (Laurie & Jensen, 2016). The RQs are the driving force for the empirical study (Yin, 2014), and are, therefore, designed in collaboration with TePe and their specific needs. The RQs are shown below.

RQ1 *How can materials supply processes to assembly lines at TePe be improved by implementing Toyota production system and Lean?*

RQ2 *Why is the materials supply processes at TePe bringing safety hazards? How can these safety hazards be minimized?*

RQ3 *How should raw materials be supplied to the new production facility?*

Defining the unit of analysis is also critical for the design of this research (Yin, 2014). The unit of analysis should be related to the way the research questions are defined (Yin, 2014), and they are, therefore, developed in tandem. The unit of analysis of this paper is defined as *materials supply processes to assembly lines in the production facility of a manufacturing company*.

It is a necessity to formulate the purpose of the project early, otherwise the choice of research method is hardly possible (Bell & Waters, 2014), later in the research process. But first, it is necessary to understand the differences between research method and research methodology. Methodology is the framework and principles of how to build the thesis, rather than specifically follow a procedure (Höst, Regnell & Runeson, 2006). Deciding on which methodology to use is based on purposes and charateristics of the study (Höst et al., 2006). Research methodology characteristics can indeed be of different nature, but Handfield and Melnyk, (1998) differentiate between five operations management purposes: (*1) discovery/description, (2) mapping, (3) relationship building, (4) theory validation* and *(5) theory extension/refinement*.

This paper builds upon the three initial purposes presented by Handfield and Melnyk (1998). Discovery/description is realized by exploring the territory of the TePe production plant. Thereafter, key variables are identified by drawing maps over the territory. By identifying linkages and ”whys” between the variables (i.e. relationship building), the map can later be improved (Handfield & Melnyk, 1998). Handfield and Melnyk (1998) recommend longitudinal, in-depth case studies to be appropriate for all of these purposes. Höst et al. (2006) also add a sixth purpose in *problem solving*. Since this paper uses the constructive approach, the final purpose is to construct solutions for TePe’s challenges, and, therefore, problem solving is the last purpose of the paper. In a Master’s thesis at any technical university, problem solving is actually the most common purpose (Höst et al., 2006).

3.4 Research Method

A tool for identifying advantages and disadvantages of research methods, and to further facilitate the choice between them is presented by Yin (2014). *Table 3.1* displays the five most common research methods, and three conditions deciding which method to choose. The conditions are: *(1)*

form of research question, *(2) control of behavioral events* and *(3) contemporary events* (Yin, 2014).

Table 3.1. Choosing between different research methods. Retrieved from Yin (2014), p. 9.

Method	***Form of Research Question***	***Requires Control of Behavioral Events?***	***Focuses on Contemporary Events?***
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/no
History	How, why?	No	No
Case study	How, why?	No	Yes

This paper is organized around research questions of the type *how* and *why*. Hence, there are three suggested strategies to follow according to Yin (2014): *(1) experimental, (2) history* or *(3) case study*. Since the materials supply is a process that the researcher cannot manipulate, like an experiment in which a few isolated variables can be measured while other variables are controlled, only two strategies remain. Finally, the focus is on real-time production, therefore focuses on contemporary events, which leads to the choice of performing a case study. As Yin and Davis (2007) put it: *"you would want to do case study research because you want to understand a real-world case and assume that such an understanding is likely to involve important contextual conditions pertinent to your case"* (p.16). Voss, Tsikriktsis and Frohlich (2002) even believe that case-based research actually is *"one of the most powerful research methods in operations management"* (p. 195). One of several strengths is the high validity with the final user of research, the practitioner (Voss et al., 2002). Moreover, Kasanen et al. (1993) state that the case study methodology is often used when applying the constructive approach.

An essential issue in case study analysis is to decide upon doing a *single case study* or a *multiple case study*. This paper uses a multiple case study, aiming for *theoretical replication*. This is what Yin (2014) describes as a multiple case study that focuses on contrasting results between cases. This paper also uses charateristics of how Ellram (1996) characterizes a single case study, in that it uses a longitudinal approach for the principal company (TePe). Since this paper uses a *constructive approach* to improve challenges at the principal company, the multiple case study basically supports the construction of solutions.

The application of a multiple case study is based on the recommendations of Yin (2014), who states that if the researcher has the time, resources and the choice of doing a multiple case study, she should. Because *"if you can do even a 'two-case' case study, your chances of doing a good case study will be better than using a single-case design"* (pp. 63-64). Having several cases increases generalizability, robustness and precludes misjudging from single events.

Individual cases in a multiple case study are either *holistic*, in which the cases are studied as a whole, or *embedded*, in which cases are studied through several units of analysis (Runesson & Höst, 2008; Yin, 2014). This paper aims on being of embedded design, which means that focus is on improving *materials supply processes* (MSP), having several, different MSPs to *assembly lines* at each company as subunits of analysis. These types of characteristics of this multiple case study are presented in *Figure 3.2*.

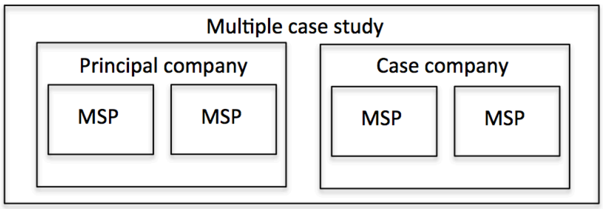


Figure 3.2. Charateristics of the embedded, multiple case study conducted in this paper, with units of analysis. Based on Runesson & Höst (2008), p. 139.

3.5 Research Process

A critical strategy for successful case study research is the reliance on theoretical concepts (Yin, 2003). This guides the design and data collection of the research (Yin, 2003). The research process used in this paper is the process which Yin (2014) presents, pictured in *Figure 3.3*. The initial step is the *development of theory*, which builds the foundation of the paper. The theoretical framework, based on a systematic literature review, corresponds to the step in this paper. *Case selection* and developing a *case selection protocol* are crucial, additional steps in designing the case study (Yin, 2014). The analysis is, then, based on *within-case analyses* for each company as well as a *cross-case analysis*. Conclusions are drawn from within-case analyses and from the replication logic used in the cross-case analysis (Yin, 2014) to finally construct the solution for TePe. Yin (2014) also greatly emphasizes the dashed-line feedback loop, which represents other discoveries than previously designed for. The concept of the feedback loop follows this paper throughout the research.

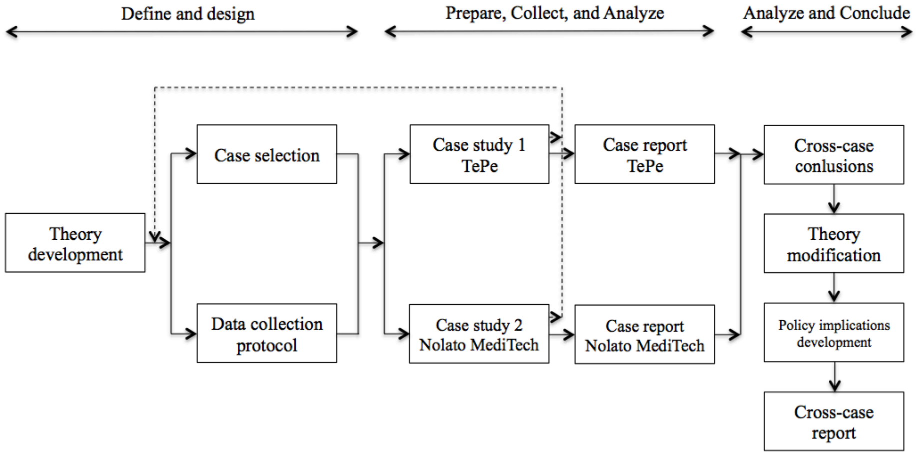


Figure 3.3. The multiple-case study procedure adopted in this paper. Retrieved from Yin (2014), p. 60.

3.5.1 Theory development

The aim for any literature review is to examine existing knowledge in the subject field, and summarize the state of the art in the field (Rowley & Slack, 2004). The summary becomes the foundation of the *developed theory* for any deductive paper. The theoretical framework used in this paper is based on the methodology for literature reviews presented by Kembro, Norrman and Eriksson (2018), illustrated in *Figure 3.4*.

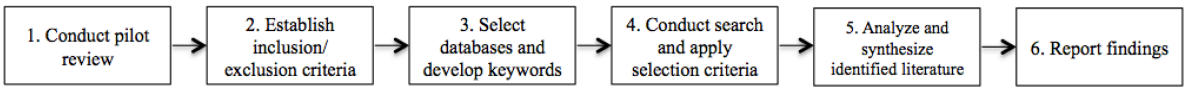


Figure 3.4. Literature review methodology. Retrieved from Kembro et al. (2018).

First, a *pilot review* is conducted to get a brief understanding of Toyota production system and Lean, with their respective terminology. The pilot review consists of a short assessment of a few books on the subject, such as Ōno Taichii's *Toyota Production System: Beyond Large-Scale Manufacturing* and Jan Olhager's *Produktionsekonomi: Principer och metoder för utformning, styrning och utveckling av industriell produktion*. In addition, Internet search engines such as *Google Scholars* is also used to get an overview (Bell & Waters, 2014; Flick, 2015). The review is, here, directed towards principles and methods used in TPS/Lean.

In the *second phase*, criteria are established for the literature review. Selected literature should have a focus on *production* or *manufacturing* and/or be related to *TPS/Lean*. No emphasis is put on either *research methods* or *publication year*, since there ought to be important sources published in the early days of the concepts. This can, in turn, decrease the accuracy of searches and, thus, loose relevant publications in a myriad of search results. Therefore, the development of keywords used in phase three is even more import. Moreover, this paper mainly refers to *peer-reviewed articles* to increase credibility.

The *third phase* consists of database selection and keyword development. Two databases are used in this paper to minimize the risk of ruling out some articles, which is in line with how Kembro et al. (2018) do their literature review. *Google Scholar* and Lund University's library catalogue *LUBSearch* are used in parallel. The theoretical framework of this paper is, therefore, based on highly respected publishers, such as *Elsevier, Emerald Insight, ResearchGate, Science Direct* and *Wiley*, recommended by Laurie and Jensen (2016). The keywords are, then, developed based on earlier phases. Keywords are divided into three categories: *(1) change initiative, (2) change initiative tools* and *(3) RQs.* The keywords used in this paper are presented in *Table 3.2*.

Table 3.2. Keywords used in this paper and number of results in the initial search.

Category	***Keyword***	***Number of results***
1. Change initiative	Lean (manufacturing/production)	113,392
	Toyota production system (TPS)	1,392
	Japanese manufacturing systems	5,165
	Process orientation	138,336
	Change initiative	97,075
2. Change initiative tools	Process mapping	125,400
	Value stream mapping (VSM)	2,536
	Operation chart	11,535
	SMED	1,682
	Kanban	1,939
3. RQ related	Materials (supply/flow/handling/management)	–
	Assembly lines	–
	Safety	–
	Efficiency	–
	Lead time	–
	Success factors	–
	Implementation	–
	Improvement	–
	Logistics	–
	Waste	–
		–

Phase four consists of *conducting the search*. Single keywords from category one and two are used in the initial phase to increase the researcher's knowledge. But keywords are soon combined using the logical operators [AND/OR] over the three categories, which quickly reduce the results. Relevant publications are, then, assessed by reading titles and abstracts. Based on the inclusion criteria as well as a subjective assessment, I reduced the number of relevant publications to some 30 articles.

An important aspect of this literature review is to follow references in relevant articles to refine the search, as suggested by Höst et al., (2006). This increases the number of publications to a final number of 54: 14 are books, 36 are journal articles, two are conference papers, one is a dissertation paper, while one is a popular science publication (web-page). The identified literature now comprises all three necessary categories of the literature review.

The fifth phase *analyzes the identified literature*. The process of following references is actually a pre-analysis of the literature, since it is what I call *literature triangulation*. Some articles are simply referred to more frequently than others, and, therefore, they become the foundation of this literature review. Publications of this nature are *”’keystone’ articles or books […] that have become ’must-cites’”* (Laurie & Jensen, 2016, p. 40) in the research field of TPS/Lean. Because as Bjurström (2016) states: *”The most successful way of improving […] must be, firstly, to learn what the pioneers once learnt; then we can do the same journey[9]”* (p. 31). Thus, relevant sources of this paper are a combination of classic literature in the field and more recent research, which Laurie and Jensen (2016) recommend. *Keystones* for this theoretical framework are presented in *Table 3.3*.

Table 3.3. Must-cites used in this paper.

Keystone	***Author***	***Publication year***
Study of Toyota Production System from Industrial Engineering Viewpoint	Shigeo Shingo	1984
Toyota Production System: Beyond Large-Scale Manufacturing	Ōno Taichii	1988
The Machine That Changed the World	James Womack, Daniel Jones and Daniel Roos	1990
Learning to See: Value Stream Mapping to Add Value and Eliminate Muda	John Shook and Mike Rother	1999
The Toyota Way	Jeffrey Liker	2004

[9] Citation is translated from Swedish.

For further analysis of the identified literature, the publications are divided into several categories based on codes (Kembro et al., 2018). Since the three RQs are already set in collaboration with the principal company, they are used as an initial code system. Another example of code is: *change initiative tools*. Based on a brainstorming session, I, then, divided each code into a few overall themes (Kembro et al., 2018) based on important aspects of a change initiative: *application, implementation, Lean comparison, critical success factors* and *challenges*. This is done to structure the forthcoming data collection and analysis, and to find potential interrelationships at the principal company within the field of TPS/Lean.

The *findings are reported* in the final stage. Each publication, divided into five themes, is presented in *Table 3.4*.

Table 3.4. Overview of themes and publications conforming with each theme.

Theme	***References***
Application	Chand (2015); Christopher (2005); Davies (1997); Dinis-Carvalho et al. (2019); Graves et al. (1993); Hall (1987); Hines and Rich (1997); Johansson and Johansson (2006); Liker (2004); Martin and Osterling (2014); Meudt et al. (2017); Modig and Åhlström (2012); Monden (2011); Ohno (1988); Olhager (2013); Persson (1996); Rother and Shook (1999); Rüttiman (2018); Shingo (1984); Suzaki (1985); Womack et al. (1990); Yamashina (1982)
Implementation	Alizon et al. (2009); Chen et al. (2010); Cortes-Robles et al. (2014); Cudney and Elrod (2011); Davies et al. (2014); Ellis et al. (2010); Islam (2016); Ismael et al. (2014); John et al. (2008); Pech and Vaněček (2018); Rother and Harris (2001); Salunkhe and Shinge (2018); Stuart et al. (2002); Yüksel and Uzunovic (2019); Zuting et al. (2014)
Lean comparison	Albliwi (2017); Gonçalves et al. (2017); Maasouman and Demirli (2016); Pigosso et al. (2013); Sundar et al. (2014)
Critical success factors	Bjurström (2016); Harrison and van Hoek (2008); Jarrell and McLain (2007); Li et al. (2006); Meredith and McTavish (1992); Näslund, D. (2008); Näslund and Norrman (2019); Ogbadu (2009); Shah and Ward (2007)
Challenges	Bhamu and Sangwan (2014); Shah and Ward (2003); Stalk and Hout (1990)

Every theme is an important aspect of a change initiative. *Application* and *implementation* are quite similar in terms of both dealing with *change initiative principles/tools*. However, a distinction can be made by asking a simple question. Application considers *what* to use in a change initiative, while implementation manages *how* it is done. *Lean comparison* tries to evaluate *why* a change initiative should take place at the outset. Both *critical success factors* and *challenges* deal with possible obstacles. CSFs, however, are more related to the necessity of different elements in the organization when applying a change initiative. Challenges, on the other hand, deals with problems that can arise if, for example, the CSFs are not in place. Lean comparison and challenges are a minor part of the total identified literature, and, thus, the cross-case analysis is conducted to increase the emphasis put on these themes.

3.5.2 Case selection

A vital question if doing multiple case studies is *case selection* or sampling (Voss et al., 2002). Miles and Huberman (1994) present two actions in sampling: (1) set boundaries and (2) create a frame. In accordance to what Miles and Huberman (1994) suggest, this paper uses its RQs to help setting the boundaries of the sampling decisions. The sampling is further based on all cases to meeting specific *criteria*, which both Eisenhardt (1989) and Voss et al. (2002) explain is common in case research when selecting cases.

Firstly, the objective of the *case selection* is to find a company working with values and principles that originates from TPS/Lean, in addition with them having implemented these methods successfully. Here, the paper aims on finding a *polar type* to TePe, suggested by both Miles and Huberman (1994) and Eisenhardt (1989) for highlighting differences in cases with contrasting charateristics. By looking at contrasting cases, there is easier to understand single-case findings (Miles & Huberman, 1994), such as at the principal company. A sample may, for example, be constructed of companies that have low or high performance in a certain aspect (Voss et al., 2002).

By delimiting the case selection to a *company that have implemented Lean,* there will be easier to find weaknesses and improvement aspects at the principal company. Since this case study requires a company to have been successful in their Lean implementation (RQ 1 and RQ 2), a criterion is that the company has been publicly noticed for their Lean commitments. Another criterion is that the case needs to be a manufacturing firm in the southern of Sweden, due to resource and time limitations of a 20-week Master's thesis. Other than that, there is no requirement on a specific industry. Finally, the company needs a higher *asset turnover* than the principal company, since that could indicate a higher efficient flow of products through the company (RQ 1).

To obtain a better understanding of which companies that have implemented Lean principles successfully, I started by using a sort of *reputational case selection* (Miles & Huberman, 1994) by asking Håkan Ivarsson, the author of *50 Shades of Lean* (2018) for suggestions. Ivarsson suggested the *Lean Forum,* a non-profit organisation supporting Lean, which each year praises a Swedish company who is successful in their Lean commitment. Then, the *funneling sampling sequence*, presented by Erickson (1986) (as cited in Miles & Huberman, 1994) is used to select companies according to each criterion, starting with award winning companies.

There are many *award winning companies* over the last decades. But as Håkan Ivarsson (personal communication, December 17, 2019) emphasizes: *"Temporary success is not hard, but sustained is. An evaluation of a Lean business captures a temporary condition (a snapshot)"*, and, therefore, I delimited the search to include both award winners and nominees but only over the last ten years. At that time, there are 25 companies left in the selection process. All of them were not manufacturing firms situated in the local area. Thereafter, five companies remained, presented in *Table 3.5*. Those companies were evaluated quantitatively on both *total asset turnover* (to understand how efficiently the company uses their assets) and *return on investment (ROI[10])* (to understand the company's profitability). The final case company is, then, reached in Nolato MediTech.

Table 3.5. A frame for the company selection and which criterias each company fulfills.

Companies	***Contact person***	***Criteria***					
		Lean Imp.	***Award winner***	***Man. firm***	***Location***	***Total asset turnover***	***ROI***
Alfa Laval AB	–	X	2012	X	Tumba, Stockholm	0.70	0.10
Atlas Copco AB	–	X	2015[11]	X	Tierp, Uppland	0.99	0.22
Astra Zeneca AB	–	X	2016	X	Södertälje, Stockholm	0.20	0.09
Gambro Lundia AB	–	X	2013	X	Lund, Skåne	0.31	0.06
Nolato MediTech	Lean coordinator	X	2015	X	Hörby, Skåne	1.57	0.18
TePe	*See Interviews*			X	Malmö, Skåne	0.64	0.20

The case study is based upon information gathered from interviews with the contact person and observations at the firm, as well as public information sources, such as *Annual Reports* and the

[10] ROI measures the ratio between profit margin and asset turnover.
[11] Nominee.

firm's webpage. Due to the time constraint, the empirical analysis and evaluation of the case company is not based on several interviewes with different employees. Neither is there any access to the case company's ERP system. Of course, not lacking in both of these aspects would have been beneficial for reliability. But, instead, extra focus is put on the *interview guide* to increase reliability. Moreover, the cross-case analysis is for comparing TePe more generally with their *polar types*, and, therefore, approximate numbers are enough.

3.5.3 Data collection protocol

Since case study research is one of the hardest research types to conduct, due to the absence of well-documented approaches, the preparation for it is more than necessary (Yin, 2014). The most vital part of preparation for data collection, especially for multiple-case design, is the development of a *case study protocol*, which, if done well, enhances reliability of the research (Yin, 2014). The study protocol describes the activities used in the research. The protocol used in this paper is based on both Yin's (2014) *study protocol model* and practical application made by Ellram (1996). There are five areas forming the basis of the protocol: *(1) overview of the case study, (2) data collection procedures, (3) interview guides, (4) data analysis* and *(5) time management*. The case study protocol is attached in *Appendix III*. For more detailed information about this Master's thesis time management, see *Appendix IV*.

3.6 Data Collection

This paper is based on a case study being primarily qualitative, which Näslund (2002) confirms is most typical for case studies. Näslund (2002) seems to yet criticize the use of traditional survey research. This is due to the simplification of quite complex ”real-world” problems, which is often of little use to the organizational practitioners themselves (Näslund, 2002). There are, in fact, usually *many cases* in case studies conducted in the area of logistics research (Näslund, 2002). Most are based on quanititative data, such as surveys (Näslund, 2002), but that can also include time-series analyses or other gathered data based on statistical analyses (Patel & Davidson, 2011). However, the researchers in those case studies do not spend any longer period of time in the companies for observation and data gathering (Näslund, 2002). Näslund (2002), then, concludes that researchers need to spend more time within organizations in the real world, and he also emphasizes the necessity of using both qualitative as well as quantitative methods to develop and advance the logistics research field.

This paper follows in Näslund's footsteps, both spending several months at the principal company and using a mixed methods approach. Both Gammelgaard (2003) and Kasanen et al (1993) confirm that a mixed methods approach is suitable for the systems approach used in this paper, as well as the constructive approach. However, qualitative research tends to work with few cases (Silverman, 2005), and this is one aspect of why this paper is primarily qualitative-based. Others are that it uses *direct observations* and *interviews* to get closer to the employee's perspective (Näslund, 2002). Both of the methods are seen as qualitative techniques (see Ellram, 1996). Since this paper applies a constructive approach, it also aims for a deeper understanding of the principal company, spending plenty of time on-site. The research, therefore, tends to be *empirical* and to some extent *interpretive*, which are qualitative charateristics (Stake, 1995). But the paper also uses some quantitative techniques, such as time-series analysis for analyzing *yearly sales data* at the principal company.

Regardless, there is actually not a clear distinction between quantitative and qualitative methods, but rather a matter of emphasis (see Stake, 1995; Näslund, 2002; Silverman, 2005). Stake (1995) highlights that all research seeks to find patterns, whether it is *correlation/covariance* (quantitative studies) or, simply, *patterns* (qualitative studies).

However, what is generally called *quantitative methods* increases statistical generizability in results and replicability (Flick, 2015). There is a risk of losing depth in the study though, and the results may be too far removed from the real world problems (Laurie & Jensen, 2016). Preferably, this paper is mainly a qualitative study, which enables an in-depth understanding of the subject, enables descriptive and exploratory investigations and allow for flexibility in making adjustments in the research design during the data collection phase (Laurie & Jensen, 2016). In general, the qualitative case study also can contribute with *analytical generalizations*, but, as mentioned, often not *statistical generalizations* (Yin, 2014). According to Yin (2014) case studies are not based on ”sampling units”, and the numbers are too small to represent any larger population (Yin, 2014). However, this paper aims for analytical generalization through *”the opportunity to shed empirical light about some theoretical concepts or principles”* (Yin, 2014, p. 40), based on its RQs.

3.6.1 Principal company

Yin (2014) describes the importance of multiple sources of evidence, creating a database and maintaining a chain of evidence to increase reliability in research. These are main ideas when collecting data for this paper. Furthermore, triangulation is another important concept (see Yin, 2014; Voss et al., 2002; Miles & Huberman, 1994), described by Ellram (1996) as a use of different techniques studying the same phenomenon. As part of a case study, some primary qualitative techniques usually used are *interviews, direct observations* and *archival research* (Ellram, 1996; Voss et al., 2002), and, as mentioned, that hold for this paper as well.

3.6.1.1 Interviews.

Interviews with key employees at TePe are conducted in a semi-structured way, based on the interview guides in *Appendix V* for management and in *Appendix VI* for operators. Shorter interviews (30 min to 1 hour) based on open-ended questions are conducted, which Yin (2014) suggests in case studies. Since *genchi genbutsu* is applied in the collection phase, naturally the amount of interviews from *operations* outnumbers the amount from *management*. However, the time spent on each interview is longer and more comprehensive for management, which balances out the time aspect. In total, there are 20 interviews conducted with employees at TePe from nine different positions, as is shown in *Table 3.6*. This serves as an important aspect since silo effects can be detected this way. The main aim of the interviews is to find general issues at TePe. An important tool when conducting the interviews is to use *5 Whys* regularly.

Table 3.6. Number of interviews and roles of each interviewee.

Area	***Title***	***Amount of interviewees***
Management	Supply chain manager	1
	Production manager	1
	Warehouse manager	1
	Production supervisor	3
	Production planner	1
Operations	Operator (Injection molding)	3
	Operator (Assembly/packing)	6
	Operator (Raw materials warehouse)	2
	Operator (Finished goods warehouse)	2
Total		**20**

Moreover, interviews are not recorded, since operations management research often focuses on objective data, and, therefore, the disadvantages of taping often outweigh its benefits (see Voss et al., 2002). I do not want the taping to be a substitute for listening, or, even worse, inhibiting the interviewee. Notes are, however, taken during the interview. But focus is to be engaged in the interview and, then, summarize everything afterwards. Voss et al. (2002) recommend that any confusion be backed up by informal conversations. The essential information of interviews is later checked and verified with the interviewee, which Voss et al. (2002) also suggest.

3.6.1.2 Observations.

The direct observations are to some extent based on the output of the interviews, which means that if, for example, several interviewees point on similar improvement areas, these are observed specifically. Anyhow, the materials flow of high volume toothbrushes is observed and mapped through visual mapping techniques such as *VSM, operation chart, time and motion chart* and *the value vs. time graph*. This is done to understand the processes relevant to the case study. At first, a key employee guides an initial *gemba walk* of the value stream to facilitate a brief understanding of all processes within the production facility. Over the up-coming months, multiple direct observations are conducted to support the visual mapping tools, primarily in quantitative terms. The most essential aspects taken into consideration during observations are found in *Appendix VII*. The guide is used in order to understand the current state, its charateristics and improvement aspects. All metrics-related observations are based on several samples, often not at the same day or even in the same week. This balances out influencing factors from the outer environment, such as variability in demand, daily performances of an operator or intense breakdowns of a machine over a period of time. However, when quantitative measurements were not possible to perform, a few operators estimated the process in question.

Field notes are an important part of the collection phase of this paper. However, Silverman (2005) states that the researcher should be aware of risks in the notes being subjective. Field notes are taken continuously when encountering important facts or ideas, either in observation, informal conversations or meetings to enhance credibility.

3.6.1.3 Archival records.

To support interviews and observations, both as triangulation and as complement for non-observable information, *archival records* are used. For example, *sales data*, *throughput times* and *article information* is gathered through TePe's ERP system. Production orders are used to estimate raw materials needed for specific products. To further understand the processes, this paper uses secondary data in terms of a previous consulting job at TePe regarding production planning.

3.6.2 Case study company

The selected case company being part of the cross-case analysis is contacted through e-mail. For an example of the initial contact or a succeeding e-mail, see *Appendix VIII* and *Appendix IX*, respectively. The case company interview guide (see *Appendix X*) is sent out to the contact persons in advance to help them prepare, in accordance to what Ellram (1996) suggests. A short agenda of what I want out of the half-day study visit is attached, including time needed for the interview and such. Since the *interview guide* is sent out in advance, all aspects can be addressed within the 1-hour interview timeframe.

All interviews are held in the interviewee's own habitat without any recordings, to increase the possibility of the interviewee answering from his/her heart. The same methodology is applied as for the interviews conducted at TePe, which means that some short notes are taken in-between questions, but the focus is rather on being dedicated the interview itself to track important answers through open-ended questions.

The interviews are divided into seven aspects, in which the funnel model presented by Voss et al. (2002) is partly used. The initial questions are broader, e.g. in the area of *context.* Thereafter, the interviews go more into detail on positive aspects such as *application, success factors* and *characteristics.* Then, more adverse aspects are brought up such as *challenges, barriers* and *improvement aspects*. Shortly after finishing the interview, a brief summary of the answers is written.

In addition with the interviews, observations are part of each study visit. The contact person and I walk *the gemba*, for me to understand both the value stream of their products and how the Lean methods are used in practice. During the observations *5 Whys* is applied as far as possible. If any ambiguities emerge later on, a follow-up is made through e-mail. Finally, for validation of their answers, relevant parts are sent out to each interviewee for approval. All feedback is, then, taken into consideration.

3.7 Analysis

In the beginning of a case study, too many researchers do not have a single idea about how evidence is to be analyzed, and, surely, the *analysis phase* is the least developed process of case studies (Eisenhardt, 1989; Yin, 2014). But that is why this paper uses a well-defined case study protocol (Yin, 2014), *early step analysis tools*, and both *within-case analysis* and *cross-case analysis*.

3.7.1 Early step analysis

In the early steps of the analysis, some methods of which Miles and Huberman (1994) strongly recommend are used to go back and forth over collected data, in parallel with generating strategies for collecting new. This paper uses a frequent overlap between data collection and data analysis (Eisenhardt, (1989). In the early process, this involves *coding, memoing* and *case analysis meeting.*

Coding is the start of the analysis (Miles & Huberman, 1994), and is fundamental for effective case research (Voss et al., 2002). This paper uses the three types of coding suggested by Miles and Huberman (1994):

- *Descriptive codes.* Directly taken field notes after observations and interviews tries to be as descriptive as possible without any interpretation. Simple codes, such as *RQ1, RQ2* and *RQ3*, to relate to each research question are used.
- *Interpretively codes.* Right after the observation or interview, the coding are reviewed and results are interpreted. Codes used are either based on possible Lean tools, such as KAN för *Kanban* etc., or on what the code influence, such as LEAD for *Lead time* etc. Other codes used are based on the charateristics of the company, such as CHA for *Challenges,* SUC for *Critical success factors* etc.
- *Pattern coding.* The coding is scrutinized to find patterns among the case itself but also against the theoretical framework (what Yin (2014) calls *pattern matching*). The coded field notes are reread periodically (Miles and Huberman, 1994).

Memos are the theorizing write-up of ideas about codes and their relationship (Miles and Huberman, 1994). Along with coding, memos are used for several ideas created in this paper – it can be personal, theoretical, methodological or of any other type. Moreover, to always stay on track – especially being a lone researcher – *case analysis meetings* are held with the supervisor at TePe weekly to summarize the current status of the case.

3.7.2 Within-case analysis

The overall idea of *within-case studies* is to strive for close acquaintance with each case (Eisenhardt, 1989). Miles and Huberman (1994) presents plenty of methods for analyses; there are probably as many approaches to case study analysis as there are researchers (Eisenhardt, 1989). Many general tactics are used throughout this paper, such as looking for (1) patterns, (2) relationships and (3) plausability, applying (4) lateral thinking, (5) clustering and (6) a chain of evidence, and making (7) comparisons (Miles & Huberman, 1994).

This paper, however, starts describing and exploring the longitudinal case, in *Chapter 4.5*, with *displays*, which is a visual format presenting systematic information for the user to draw valid conclusions (Miles & Huberman, 1994). Many of the TPS/Lean visual mapping techniques are used to display relevant information at TePe. There are also a *time-oriented display* in yearly sales data to predict a future material flow (see *Chapter 4.2*). After observations and interviews, which are structured in a *role-ordered matrix* to understand important information from key employees, TePe's most critical challenges are presented. Further on, each case company is analyzed using a *conceptually ordered matrix* with this paper's TPS/Lean maturity model as foundation (see *Chapter 5.1.3* and *Chapter 5.2.3*). Each case company's profitability and asset efficiency is also analyzed through a Du Pont analysis using a time-oriented display over the last decade (see *Chapter 5.1.2* and *Chapter 5.2.2*). Both the conceptually ordered matrices and the time-oriented displays are, then, the basis of the cross-case analysis in *Chapter 6*.

Next step of a within-case analysis is to look for explanation and causality (Miles & Huberman, 1994). A powerful tool is *causal networks*, relating the most important dependant and independant variables into a coherent picture (Miles & Huberman, 1994). This paper builds a causal network for the Lean implementation process at Nolato to understand a generic TPS/Lean implementation process (see *Chapter 5.2.7*). A similar causal network for a possible TPS/Lean implementation at TePe is, later, built to guide a future implementation (see *Chapter 7.3*). Moreover, I do a few analyses in early Chapter 7, which, basically, are displays of TePe's machine capacity influenced by important TPS/Lean variables. A *scatterplot*, which is suggested by Miles and Huberman (1994), also shows this bottleneck identification (see *Chapter 7.1.2*). Finally, another scatterplot is used to analyze the actual constructed recommendations for TePe in regards to (1) execution ease and (2) anticipated benefit (see *Chapter 8.3*).

3.7.3 Cross-case analysis

A key step in case research is to systematically search for cross-case patterns (Voss et al., 2002). Miles and Huberman (1994) present 22 different methods for cross-case analysis. Due to time limitations, this paper uses only a few of them for exploring and describing, and, later, ordering and explaining, which is the preferred methodology presented by Miles & Huberman (1994).

The conceptually ordered matrices from each case company are displayed in a gap analysis to both understand TePe's actual and potential degree of TPS/Lean implementation (see *Chapter 6.1*). As for the time-oriented displays from each case company, they are displayed in a *time-ordered scatterplot* based on (1) asset turnover and (2) profit margin to understand how these dimensions have changed over the decade (see *Chapter 6.2.1*). I also make use of cross-case patterns for similarities and differences between the companies in efficiency and safety. Other dimensions (i.e. strategy, characteristics, success factors and challenges) are chosen by the author of this paper, which Eisenhardt (1989) proposes as a possibility, to show overall similarities and differences between cases and support for cross-case conclusions to be drawn. Not only is a cross-case analysis important for finding gaps between the case companies, but also to increase the external validity of the findings in the TePe case study (Voss et al., 2002).

3.8 Contextual scheme of Master's Thesis

It is crucial to have a view over what is intended to be studied and the relationship between these categories prior to abovementioned empirical data collection and analysis (Voss et al., 2002). I have, therefore, structured a contextual scheme over this Master's thesis sections, related to each chapter, which is presented in *Figure 3.5*. Each chapter has an impact on the other, leading up to final recommendations in *Chapter 8*. Note the four elements building a constructive research approach, i.e. theoretical connection and contribution as well as practical relevance and functioning, which are all illustrated in the figure. Since a demonstration of practical usability is paramount for scientific validity (Kasanen et al., 1993), two workshops are held with key employees to increase the validity of the paper. There is also an introduction of the Master's thesis to relevant blue-collar workers, as an activity kick-off, since a cornerstone of TPS/Lean is *people*. Practical information about the *Introduction* can be found in *Appendix XI*.

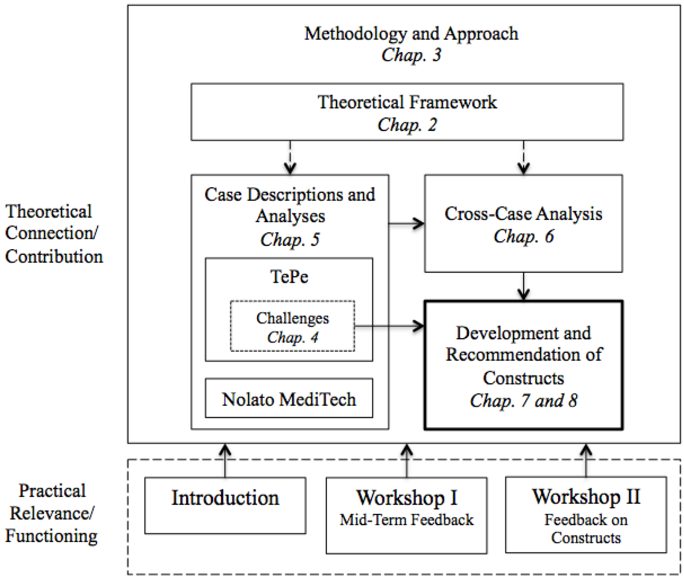


Figure 3.5. Contextual scheme of Master's thesis.

3.9 Research Design Quality

Several researchers discuss the criticism that case-study based logistics research have endured regarding its rigor and credibility (see Ellram, 1996; Stuart, McCutcheon, Handfield, McLachlin & Samson, 2002; Pedrosa, Näslund & Jasmand 2012).

However, Ellram (1996) argues that there is actually a misconception that case studies do not use a rigorous design methodology. Thus, demonstrating in her *Journal of Business Logistics* 45-page research paper ”The Use of the Case Study Method in Logistics Research” that case study methodology involves both rigorous design and vigorous analysis if used correctly. Key in attaining credibility for case study research is by establishing clear and exact procedures that are displayed in full detail, which, in turn, give the readers a possibility to judge the methodology themselves (Ellram, 1996). Ellram (1996) leads by example in explicitness by providing an extensive study research plan and interview guide.

The constructive research has also met some criticism regarding the methodological process not being scientific enough (Kasanen et al., 1993). This criticism can, however, be avoided through properly planning and execution of the research (Stuart et al. 2002). Kasanen et al. (1993) demonstrates that the constructive approach is a step-by-step procedure, with the possibility to check every step, and the procedure has a definite purpose. The approach also shares the characteristics of *applied science* in: *(1) relevance, (2) easiness to use* and *(3) simplicity* (Kasanen et al., 1993). All of the abovementioned aspects answer to the most significant charateristics of science (Kasanen et al., 1993).

Yin (2014), along with many other authors, provides more general guidelines for enhancing validity and reliability in case study research. The conventional four criteria for judging the quality of research design, based on positivism, is *(1) construct validity, (2) internal validity, (3) external validity* and *(4) reliability* (see also Ellram, 1996; Näslund, 2002; Stuart et al., 2002; Voss et al. 2002; Halldórsson & Aastrup, 2003). Miles and Huberman (1994) mention a few more, but it is particularly important to pay attention to validity and reliability in case study research (Voss et al., 2002). How this paper applies each criterion is discussed below.

3.9.1 Construct validity

Construct validity is the criterion that addresses much of the attracted criticism (Yin, 2014). The criterion refers to how well *correct operational measures* are established for the concepts being studied (Ellram, 1996; Voss et al., 2002; Yin, 2014). Ellram (1996) and Yin (2014) discuss three elements available to increase contruct validity: *(1) multiple sources of evidence, (2) chain of evidence* and *(3) draft review by key informants.*

This paper uses *multiple sources of evidence (triangulation)* in four different ways presented by Patton (1999). By using several data collection methods, such as interviews, direct observations on-site, archival records and internal company memos, *methods triangulation* is achieved in this paper. By, for example, interviewing 20 informants from several positions, *triangulation of sources* is obtained. *Analyst triangulation (review findings)* is attained through two workshops, regularly meetings with principal company supervisor and through verification of results from data collection and analysis. Both root causes and challenges that TePe faces as well as the application of this paper's TPS/Lean maturity model on TePe's business is roughly validated by some key employees at the company. The workshops, in particular, are important to increase the overall quality of the final recommendations.[12] Finally, several analysis methods are used striving for *perspective triangulation*.

In the case of this report, the *chain of evidence* is verified by the supervisor[13] at LTH reading through the entire document a few times over the 20-week period.

For *draft review by key informants,* see analyst triangulation above.

3.9.2 Internal validity

Internal validity is to which extent there is a causal relationship between one event leading to the other event (Yin, 2014). Are the findings credible to participants and readers (Miles & Huberman, 1994)? In this paper, *pattern coding* and *pattern matching* against existing literature, as well as *time-series analyses*, are used to enhance the criterion.

3.9.3 External validity

Are the findings transferable and generalizable to other contexts (Miles & Huberman, 1994)? A multiple case study increases *external validity* in comparison with a single case study (Voss et al., 2002). Moreover, by using a replication logic (theoretical replication), the transferability is increased further (Pedrosa et al., 2012). Since this case study provides well-defined units of analyses and a justification of case selections[14], the chances of generalizable findings are higher (Pedrosa et al., 2012).

3.9.4 Reliability

Reliability addresses the repeatability of a study (Ellram, 1996). If the same procedure is used, a later researcher can conduct the same research and come to find same results and conclusions (Yin, 2014). Yin (2014) suggests two tactics for enhancing reliability: using a *case study protocol* and developing a *case study database*. Both tactics are used in this paper. Except the case study protocol, *interview guides* and *example of introduction e-mails* are attached in Appendices. The case study database has pictures of field notes, notes from interviews and printed material that case companies provided during the research. For a summary of indicators that enhances different quality criteria in this paper, see *Table 3.7*.

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[12] The recommended constructs are validated and assessed by key employees in Workshop 3 (see *Appendix II*). The constructs averaged 2.5 on a score from one to three (1 – ”not considered, 2 – ”considered” and 3 – ”definitely considered”).

[13] Professor Andreas Norrman has won several Emerald Highly Commended Awards as both author and reviewer (Lund University, 2020).

[14] Since the sample of cases is quite small, extra effort is put onto the case selection process.

Table 3.7. Summary of quality criteria applied into this paper.

Quality criteria	***Indicators in this case study***
Construct validity	❖ Multiple sources of evidence (triangulation) ❖ Chain of evidence ❖ Draft review (two workshops) of key informants regularly
Internal validity	❖ Pattern coding/matching ❖ Time-series analysis
External validity	❖ Defined UoA, case study protocol and interview guides ❖ Justification of case selection (theoretical replication) ❖ Multiple case study ❖ Replication logic for cross-case analysis
Reliability	❖ Case study protocol ❖ Case study database

3.9.5 Objectivity and ethical research

Miles and Huberman (1994) present *objectivity* as another criterion for judging the quality of research. Throughout the research of this paper, I strive for *neutrality* and *avoidance of bias* in every aspect by implementing the indicators shown in *Table 3.7* above. However, there may always be researcher bias based on personal assumptions and values. I, therefore, try to explicitly show conclusions and be open to contrary findings (Yin, 2014).

The same holds for this paper striving for ethical research. The case study follows ethical guidance such as *informed consent* (through e.g. an information workshop)*, honesty* and *confidentiality and anonymity* (through agreements and review of case study report).

Chapter 4. Materials Supply Processes and Challenges at TePe

This chapter presents the empirical study of the principal company (TePe). Initially, a few delimitations of this paper are stated, followed by descriptions of the operations in manufacturing a toothbrush at TePe. The chapter moves over to studying the value streams of toothbrushes through visual mapping techniques. Challenges related to each research question are identified. The chapter is concluded with the most prioritized current challenges TePe faces.

4.1 Introduction

The research questions were, as mentioned, narrowed down to incorporate one product category, *toothbrushes*, based on a close collaboration with TePe. However, after some research and some on-site observations, I found out that there is a great variety of toothbrushes in different models in many different colors. Only over the last couple of years, TePe has introduced several new products to the market. Today, they have 19 different products in their product portfolio, along with some being manufactured in eight different colors. Add to that toothbrushes that are sold in different multi-packages: one, three, four and six pieces per package. In total, this adds up to around 108 SKUs only for toothbrushes in different colors. To be able to conduct a sharper analysis, this paper therefore examines two categories of toothbrushes: (1) a high volume category and (2) a low volume category.

4.2 Sales Volumes and Product Selection

To understand yearly volumes of sold toothbrushes, sales data is collected from the ERP system. This basically highlights which products are more important to the company in regards to *sales volumes*. This is essential for further construction of possible solutions, since it can have an impact on everything from *production planning prioritizations* to *material flows* in the production facility and the construction of *new layouts* etc.

Since TePe changed their ERP system some years ago, the sales data is limited to 2015-2018. In total, TePe had a sales volume of around 19.9 million toothbrushes in 2019. Since they strive for a yearly overall organic growth of 10-20 per cent, this value is most likely to increase over the following years. Based on the last six years' sales volumes, however, TePe has had an organic growth for their toothbrushes of 5.4 per cent.

A *pareto chart* is established to evaluate the sales volumes of each and every product of toothbrushes and their correlation to each other, which is in line with Hines and Rich (1997). In this case, sales volumes correspond to sales revenues, since each product share the same manufacturing steps and there are only small differences in prices. *Figure 4.1* shows that 90.0 per cent of total sales of toothbrushes is spread out over six products, which are seen as high volume products (HVP).

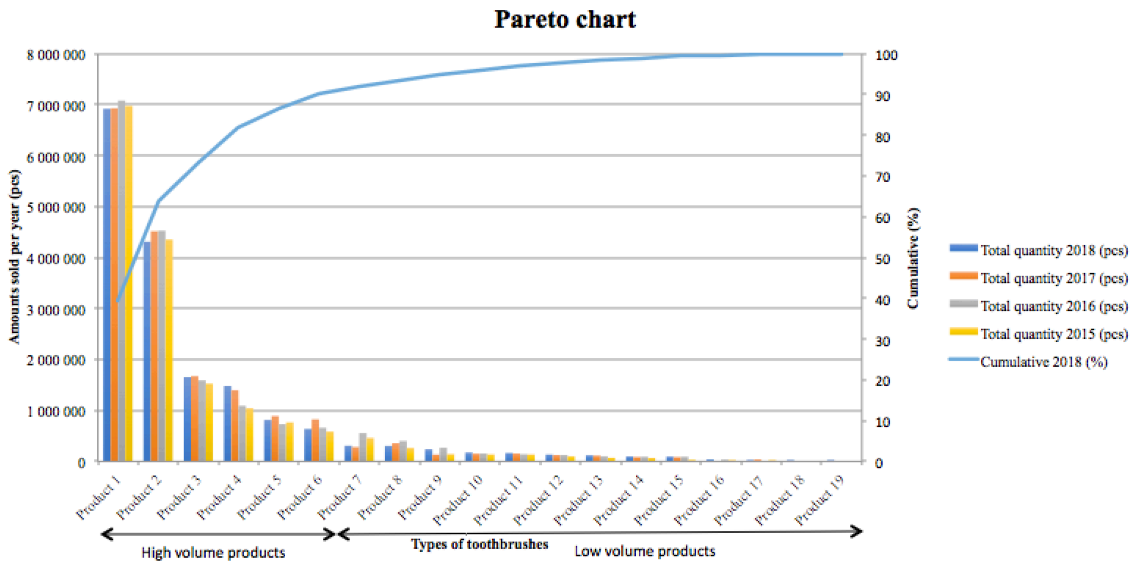

Figure 4.1. Pareto chart over the amount of sold toothbrushes for each category for 2015-2018.

Product 1 is further evaluated in more detail, representing HVPs, since the product by far is the most important product for TePe, besides *Product 2*. Products in the middle range (*Product 11-15)* of low volume products (LVPs) are used for the evaluation of LVPs, since they probably represent an average in regards to what is studied. Moreover, the yearly sales data is assumed to be the actual yearly demand later in the analysis.

4.3 Current Production Facility

Today's production facility can be divided into different areas of operations, since TePe primarily uses a functional layout for their production. *Figure 4.2* illustrates the production facility layout, highlighting the most important areas of operation in regard to this paper. There are areas for (1) receiving/shipping, (2) raw materials warehouse (RMW/TEPE2), (3) injection moulding, (4) intermediate storage (TEPE3), (5) assembly/packaging (PROD3), (6) finished goods warehouse (FGW/TEPE2), as well as (7) one area for production of other products and (8) another for the new production facility[15].

[15] Internally at TePe, the areas have different names. They are used interchangably with this paper's more logical abbreviations. Moreover, due to confidentiality, each area within the layout of *Figure 4.2* is grey-colored.

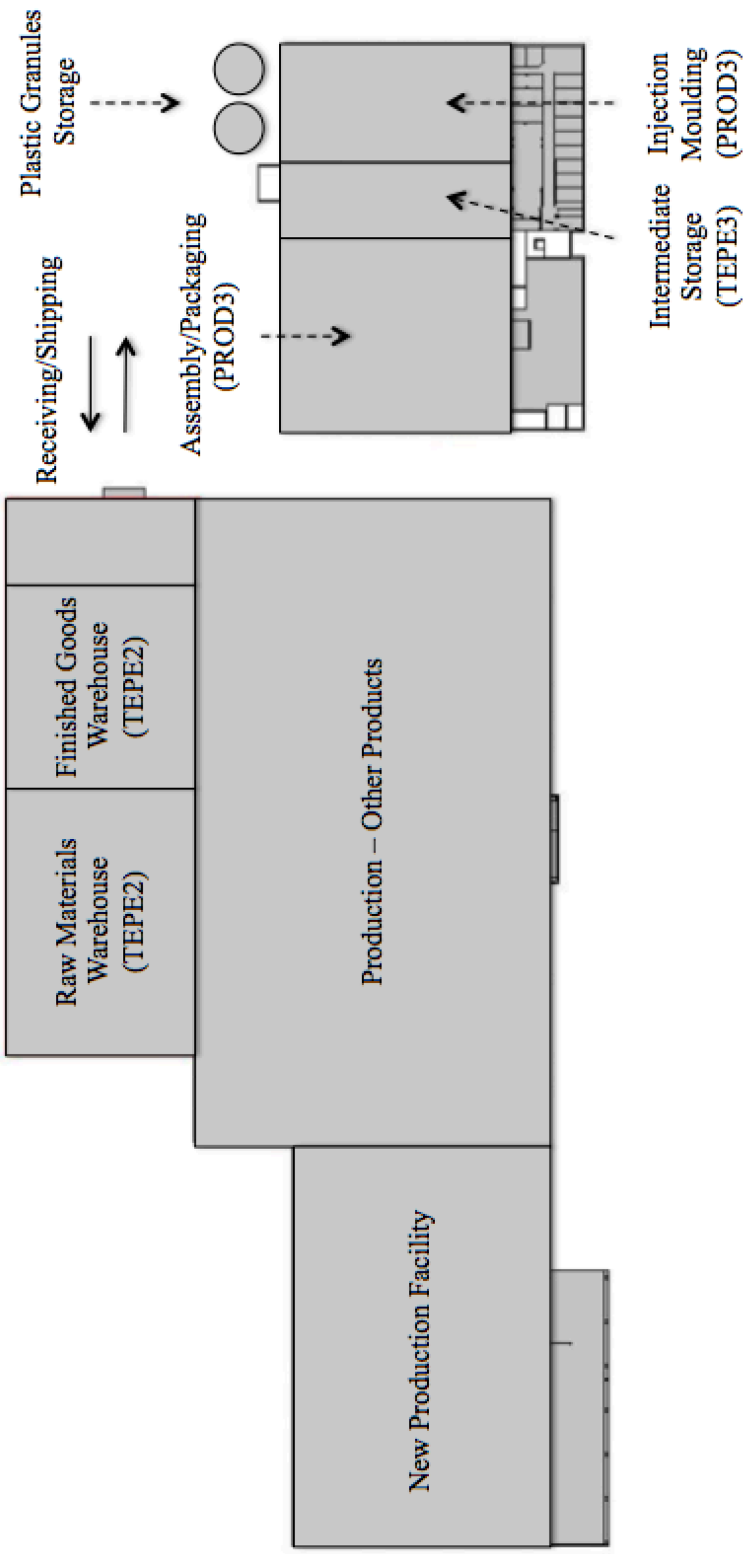

Figure 4.2. Production facility layout over the product category toothbrushes.

4.4 Operations

The operations included in manufacturing a toothbrush at TePe consists of four main steps: (1) injection moulding, (2) mixing, (3) assembly and (4) packaging. *Figure 4.3* highlights these operations in a brief overall operations chart. The figure also highlights an operation's value-adding attribute to customer and in which area of the facility layout the operation/storage takes place.

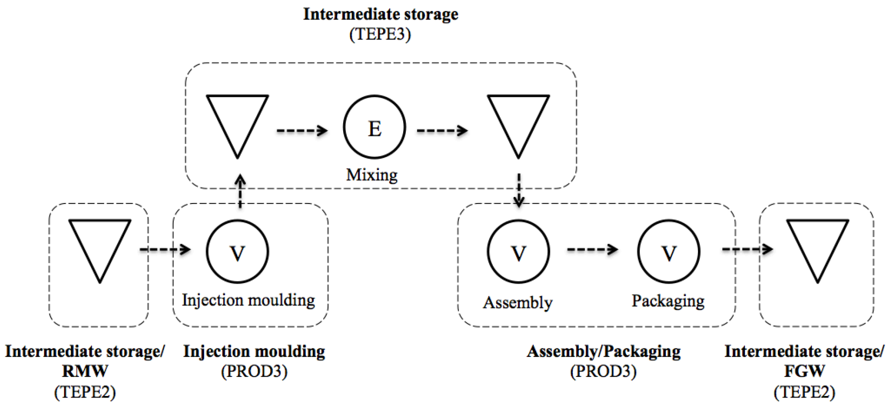

Figure 4.3. A brief operations chart over the steps required to manufacture a toothbrush at TePe, as well as in which area each operation and storage occur.

Basically, the first step moulds the handles of the toothbrush. The next step mixes the different colors of handles prior to the assembling of filaments. The finished toothbrush is now ready for the final step: packaging. All operations but mixing are seen as VA activites. There can be argued, however, that mixing is a VA activity as well, since customers may value having different colors in a multi-package. In this paper, the operation is, therefore, seen as an ENVA activity. A more thorough description of the steps in manufacturing a toothbrush at TePe follows.

4.4.1 Injection molding (PROD3)

In the process of injection moulding, raw materials such as *plastic granules* and *color granulates* are mixed and moulded into handles within the machine park located in what TePe calls PROD3. The current capacity of this machine park as well as the handling of materials being part of this operation are discussed below.

4.4.1.1 Capacity.

There are a total of 14 injection moulding machines in PROD3. The machine park of this operation is fully automated. However, each machine has the capability of manufacturing only a few different products, but all colors. Needless to say, one batch obviously consists of one product in one color. A setup is, then, required in-between batches. Moreover, the machines have pre-installed setups for suitable *cycle times*, *injection times*, *cooling times*, *positions of tools* etc. to produce each type of stock keeping unit (SKU) with high quality.

While the machines run, technicians oversee them and solve problems if there are any breakdowns. If no breakdowns occur, the machines can produce full batches without operator supervision. The technician continuosly checks samples of the output visually to ensure high quality. For example, they inspect the shape and the surface for any defects. Each technician knows the standards by heart. If the handles do not meet specifications, the technician adjusts the settings on the machine.

During the day shift, there is one technician overseeing all 14 injection moulding machines for toothbrushes. However, the machines are planned to run around the clock, having one technician overseeing all injection moulding machines at the plant (39 in total for all products) during the remaining shifts.

4.4.1.2 Materials handling.

All machines have plastic granules transported as input through pipes connected with two silos outside of the production plant. Technicians do only transport sacks of color granulates and pallets of empty transportation boxes to the machines from intermediate storage. Then, their responsibility is to start the production of handles by setting up the machines. The machines mould the handles, let them cool while moulding new handles, and, then, automatically move the handles to the empty transportation boxes which have room for 300 SKUs each. There are 48 transportation boxes on a pallet, which means that the company generally strives for batches consisting of approximately 14 400 handles for all their different products. However, the technician finally transports the pallet into the intermediate storage using a pallet jack. He drops the pallet on the warehouse floor in a predetermined area in the middle of an aisle. The area is not painted.

4.4.2 Intermediate storage (IS or TEPE3)

There is an intermediate storage used between several different operations, but mainly in-between injection moulding and assembly/packaging.

4.4.2.1 Capacity.

The current intermediate storage (IS or TEPE3) at TePe has a size of 437 m^2 with 456 pallet positions. A quarter of them are located on the bottom shelves, assigned *fixed pallet positions*[16]. These fixed pallet positions are reserved for up-coming production orders. A SKU is assigned one or several fixed pallet position based on the production planner’s forecast. This comprises

[16] This is translated from what TePe internally calls ”dragningsplatser”.

alterationes between production plans. There are 114 fixed pallet positions of today; 29 of which are assigned raw materials and the rest handles.

There are also *normal pallet positions* within TEPE3 that are primarily assigned SKUs of different handles, which are later used as a buffer for future demand. There are, however, a few[17] pallets of raw materials stored in this area due to warehouse operator's not putting away pallets with residuals in the RMW after replenishment, since the residuals will be used in another raw materials replenishment to the production later on anyway. A snapshot of the buffer gives 16 different SKUs of handles in 62 various colors.

Moreover, there is a *paternoster lift (TLIFT)* connecting TEPE3 with assembly/packaging. The lift consists of some 71 different SKUs of raw materials. When the TLIFT is fully utilized, it takes up an estimated area of 52 m^2, accounting for all 13 shelfs.

4.4.2.2 Materials handling.

The warehouse operators put away the batches of SKUs recieved from injection moulding that are stacked one pallet high directly on the warehouse floor. There are four warehouse operators working over two shifts, and they check TEPE3 at least twice a shift. Therefore, the batches often wait on the floor for a shift (eight hours) before the warehouse operators are aware of them. The batches are, then, transported to available normal pallet positions used as the buffer within TEPE3. The warehouse operators also manually check fixed pallet positions and digitally check the TLIFT for replenishments. In this way, these positions are easily accessible for the assembly/packaging operators.

4.4.3 Mixing

Mixing is the second step in manufacturing a toothbrush at TePe. Since a batch is injection moulded in a single color, and toothbrushes often are sold in multiple packages containing one color each, many batches require mixing colors into new batches. Operators do this manually. Moreover, the operation appears *before* assembly/packaging, since the latter is emerged into one automatic sequence without storage in-between.

Safety is a corner stone at TePe, yet mixing is performed in an area within the intermediate storage in which operators coexist with forklifts. Two reasons for this is accessibility and space constraints.

Finally, mixing is seen as an ENVA acitivity in this paper. This is due to mixing not being a VA activity *per se*, but may be seen as one for some customers. There may, for example, be

[17] At the time of the analysis, there were 15 pallets of raw materials.

customers, such as families, valuing a mix of colors when they buy a multi-package of toothbrushes.

4.4.3.1 Capacity.

There is a scheme for mixing, which includes all assembly/packaging operators. Each day shift, a new operator mixes. In theory, the restriction of capacity is the number of operators and the area of operation. However, today *one* operator daily do the work of mixing.

4.4.3.2 Materials handling.

The assembly/packaging operator picks transportation boxes of different SKUs from the fixed pallet positions. For example, Product 1 could be mixed in six different colors to enable for packaging of a six pieces multi-package. As output of mixing, there are batches, still around 14 400 pcs each, of mixed colors of a single product, in this example, Product 1. The batches are, again, put away in intermediate storage prior to assembling.

4.4.4 Assembly/packaging

The third and the fourth step in manufacturing a toothbrush at TePe are linked together in an automated machine park. First, *assembly* joins the filaments with the handles, which are newly printed with a TePe logo. The machines, then, automatically move the finished toothbrushes onto a conveyor belt connected with packaging. Second, the toothbrushes are packed in either a single or multi-package (three, four or six).

4.4.4.1 Capacity.

There are ten stations in this machine park in total. A station includes both assembly and packaging, with a single operator appointed responsibility for a particular station each shift. The machines are, however, arranged in such a way that walking distances are minimized. Additionally, there is at least one operator appointed an overall responsibility helping others in need. Thus, generally there are 22 operators working over two shifts.

Generally speaking, the machines need no supervision. However, if any breakdowns occur, the operator informs a technician. In either case, the responsible operator performs a quality inspection on the conveyor belt in-between operations. Defects such as missing or too short filaments, as well as misprints, are either scrapped or transported to developing countries depending on the state of the product. Finally, the number of produced toothbrushes and defects as well as break-down times are manually documented by the operator after each shift.

4.4.4.2 Materials handling.

There are totally 66 fixed pallet positions spread around the assembly/packaging area, of which 16 are assigned for specific raw materials. 20 pallet positions are assigned SKUs of handles as input and output to stations. The rest seems to be unstructured positions with, for example, extra handles, damaged goods etc.

Operators pick up raw materials and handles either from these fixed pallet positions or from the ones in TEPE3. Input to assembly is batches of SKUs of handles in mixed colors. Moreover, high-volume raw materials for assembly are *filaments*, *anchor wire* to attach the filaments and *stamp foil* for the TePe logo. For packaging, high-volume raw materials includes *primary* and *secondary packages*[18].

Finally, the operator packs the toothbrushes in those packages and puts them onto an empty pallet. A full batch is, then, moved to TEPE3 using a pallet jack. The warehouse operator transports the batch into the FGW.

A summary of capacity and materials handling of each operation is illustrated in *Figure 4.4* below. In the current layout, there are in total 44 pallet positions and 75 shelving positions only for raw materials. This means a total of 119 different SKUs of raw materials. For more information about the amount of positions for each specific SKU, see *Appendix XII*.

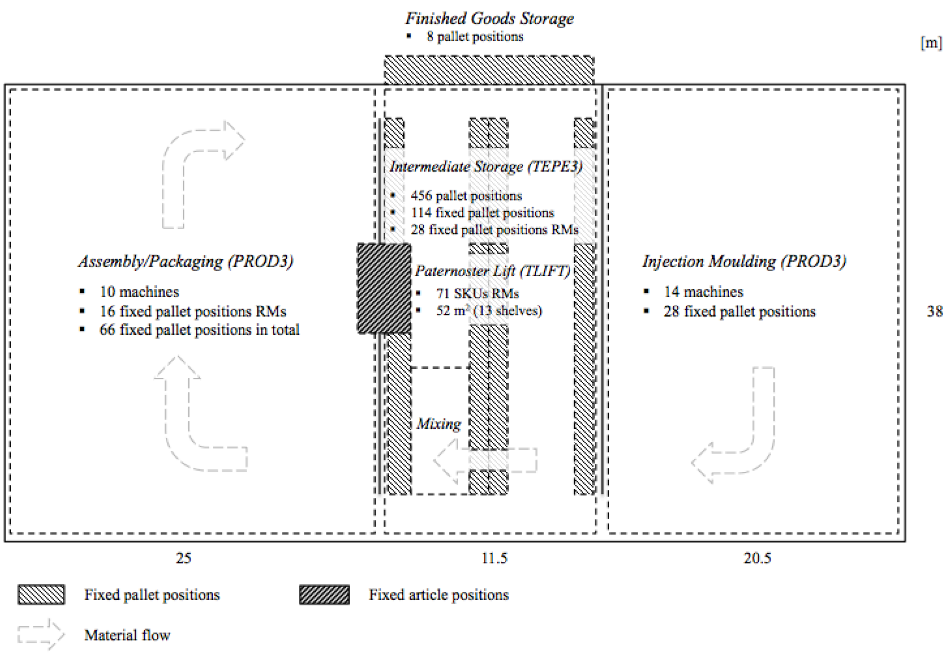

Figure 4.4. A summary of capacity and materials handling of each operation in the current layout for TePe toothbrushes. RM is an abbreviation for raw material.

[18] Internally, TePe calls them ”detaljistförpackning” and ”transportförpackning”, respectively.

4.5 Visual Mapping Techniques

Four visual mapping techniques are used to understand the characteristics of TePe's value stream for toothbrushes. Due to their different perspectives, characteristics and various advantages (or lack of them), they serve as a thorough data collection process to find out challenges for the company. This, then, provides the foundation of the within-case analysis. The methodology used is presented for the reader in the theoretical framework *(Chapter 2.13)*.

4.5.1 Value stream mapping

In this paper, a *value stream mapping charter* is first prepared with all relevant information about the VSM data collection, which is in line with what Martin and Osterling (2014) suggest since preparation is probably the greatest success factor of conducting VSM (Martin & Osterling, 2014). The main objectives are to understand the value stream and its operations in regards to efficiency (RQ1), but also in regards to safety (RQ2). Measurable variables are primarily lead times and processing times. The VSM charter is, further, verified by the supervisor at TePe, and also presented in the *Introduction* to inform relevant operators about the data collection, which is also recommended by Martin and Osterling (2014). A more detailed description of *Introduction* is attached in *Appendix XI*.

4.5.1.1 Current state.

The VSM represents HVPs, conducted for *Product 1* and illustrated in *Figure 4.5*. The *information part* of the VSM is based on interviews. The *material flow part* is primarily based on direct observations of the production. *Processing times* and *cycle times* are measured using at least 25 samples over a period of different days. However, the *lead times* (including *waiting times*) are based on operator/management estimations and some ERP information. Lead times are, later, verified using Little's law and secondary data from a hired consulting firm. The VSM presents average values[19] of *PTs, CTs, WTs, batch sizes* and *%C&A*. *LTs* are based on the ratio between *CTs* and *batch sizes*.

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[19] Due to lack of accessibility of information from the ERP system, extreme values such as min and max are not considered even though that could have given further insights of the charateristics.

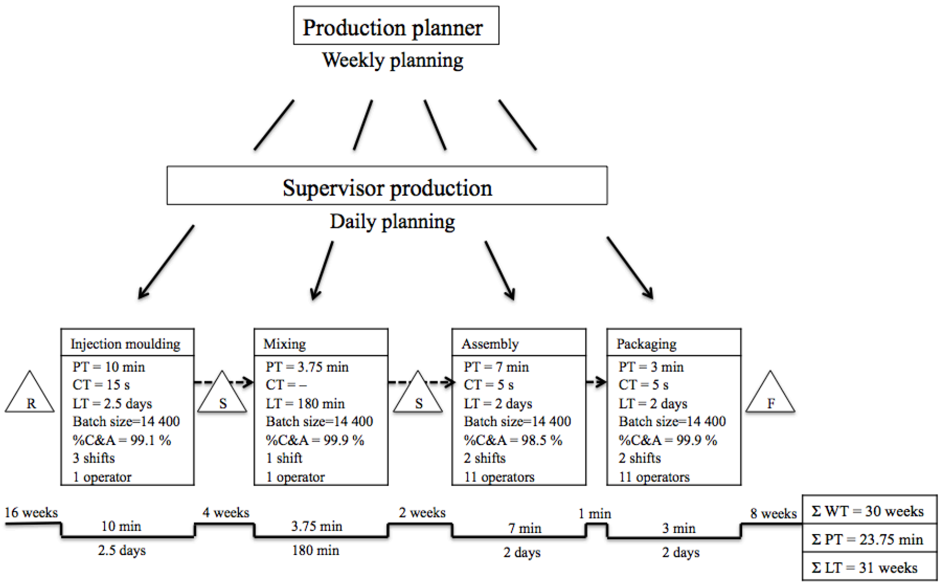

Figure 4.5. Value stream mapping of Product 1.[20]

In average, a HVP spends months in the production facility even though the processing time (i.e. VA activities) are no more than around 24 minutes a toothbrush. The main reason for this is a product's long waiting time in storage in-between almost every operation.

Since the LTs reach 31 weeks before a finished product is delivered to customer, the activity ratio is hardly 0.03 per cent. For each operation, LTs are affected by batch sizes due to products waiting in front of the operation as well as after. Moreover, the *rolled % complete & accurate* is 97.4 per cent.

Since the processes of a HVP are similar to the processes of LVPs and similar batch sizes are used, there is no difference in PTs. There are differences, however, in production planning between the two. Naturally, HVPs are manufactured more frequently than LVPs due to differences in demand. This leads to LVPs often spending more time in intermediate storage (around three weeks extra) as well as in FGW. However, since the activity ratio is remarkably low already, the differences between HVPs and LVPs are low and seen as insignificant for this paper.

4.5.1.2 Production planning.

In the production planning process, the planner examines historical data in the ERP system to be able to forecast on a weekly basis. The production planners, then, send a weekly production plan to each production supervisor, who plans the daily production in more detail. This is illustrated in *Figure 4.5* above. However, there needs to be daily alterations in the production plan due to insecurities in forecasts, long production lead times and long setup times. Moreover, even if

[20] *R* represents RMW, *S* represents intermediate storage and *F* represents FGW.

standard batch sizes in general are a pallet (i.e. approximately 14 400 toothbrushes), the orders usually differ in size.

Many decisions are often taken based on experience by both the two production planners and the production supervisor. However, TePe has recently tried to implement an *order point system* to ease the decision making for the production planners. The inventory on hand is updated in real time in the ERP system. Based on the production lead time for a product, the production planners initiate orders to secure a safety stock of four weeks. The safety stocks are also based on historical sales volumes. Mattsson and Jonsson (2003) call such a reorder system *cover-time planning*, since the required stock is based on time rather than quantity.

4.5.2 Value vs. time graph

Since the VTG enables strategic decisions on a macro-level by visualizing how value is added over time, it is presented in *Figure 4.6* as a complement to the VSM. The graph also includes *replenishment time (shipment)* from suppliers and an average *delivery time* to TePe's subsidiaries. These aspects are based on internal documentation from TePe. The area beneath the graph is the value of tied-up capital. Focus is to reduce tied-up capital later in the system, since this increases the value of inventory with a greater factor than tied-up capital earlier in the system. *Figure 4.6* shows that there is plenty of tied-up capital in TePe's inventory, especially since the products are semi-manufactured and then stored in intermediate storage, or even worse FGW, for several weeks.

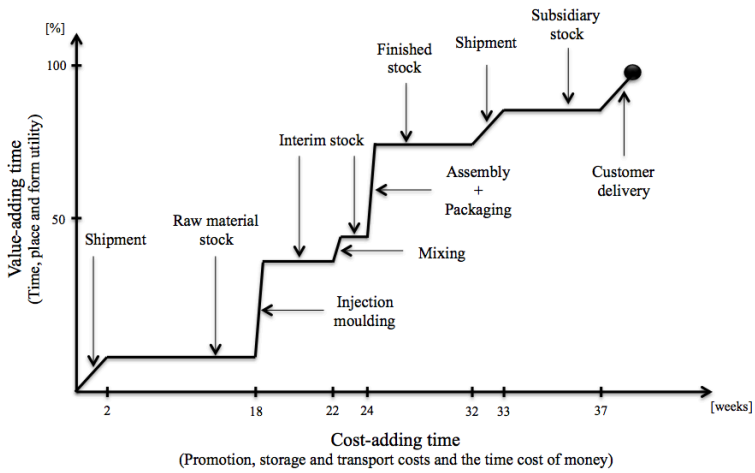

Figure 4.6. Value vs. time graph for Product 1.

4.5.3 String diagram

Operations at TePe are primarily arranged according to the *functional layout*, i.e. machines with same characteristics based on the manufacturing perspective are arranged near each other. For example, there is one area for injection moulding and another for assembly/packaging. However, the production facility may be called a hybrid of a functional layout and a *cell layout* since a packaging machine is arranged next to each assembly machine. TPS/Lean favors a cell layout (see e.g. Schonberger, 1983; Yamashina, 1982; Liker, 2004). Partly arranging in a functional layout has an impact on TePe's entire material flow since it requires multiple storage areas, leading to the wastes of *unnecessary transportation* and *excess inventory*. The string diagram in *Figure 4.7* visualizes a general flow of a product through the production facility[21].

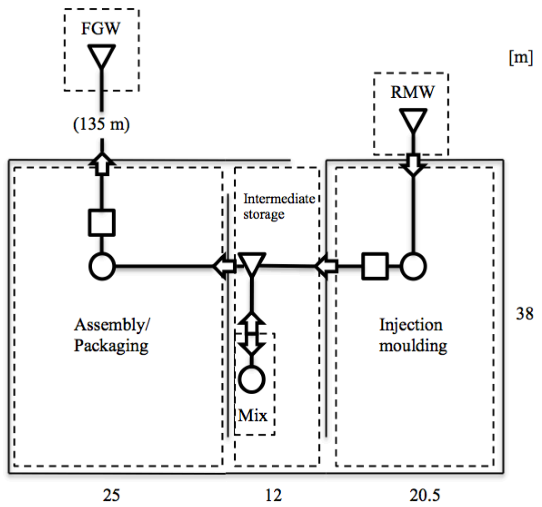

Figure 4.7. String diagram (spaghetti diagram) of the production areas delimited to toothbrushes at TePe.

Using a functional layout, in general, increases flexibility in the sequence of processes (Olhager, 2013). At TePe, however, the process sequence is not very complex and products need to pass through all processes in a particular order, which means that the flexibility is insignificant. Drawbacks of using a functional layout is instead that there is a risk of products piling up, leading to *long waiting times*, *long lead times* and *increased tied-up capital* (Olhager, 2013), which happens at TePe. *Figure 4.7* also illustrates that the product travels back and forth in-between mixing and intermediate storage, instead of having an aligned flow.

4.5.4 Operation chart

Since the operation chart accounts for the entire process (i.e. processing, inspection, transportation and storage) step-by-step, it is used in this paper. Considering safety being a RQ measured in the form of transportation distances by forklifts, the operation chart is a valuable tool since it visualizes this aspect. The operation chart is based on the string diagram, but it delves into each step of the system. The operation chart for toothbrushes is illustrated in *Table 4.1*.

[21] The symbols are universal, but in any case described in the theoretical framework (Chapter 2.13).

Table 4.1. Operation chart for a batch of toothbrushes at TePe.

Operation chart (Time & motion chart) for a batch of toothbrushes								
Current process								
Step	***Description***	○	⇨	□	▽	***Time (weeks)***	***Distance (m)***	***Value code***
1	In storage				x	16		N
2	To injection moulding		x				19	N
3	Injection moulding	x				-		V
4	In injection moulding				x	0.5		N
5	Inspection			x		-		E
6	To intermediate storage		x				54	N
7	In intermediate storage				x	4		N
8	To mixing		x				25	N
9	Mixing	x				-		E
10	To intermediate storage		x				25	N
11	In intermediate storage				x	2		N
12	To assembly/packaging		x				37.5	N
13	Assembly/packaging	x				-		V
14	In assembly/packaging				x	0.5		N
15	Inspection			x		-		E
16	To finished goods warehouse		x				135	N
15	In finished goods warehouse				x	8		N
Sum		3	6	2	6	31	295.5	-

The operation chart shows that each batch is transported approximately 300 metres within the production facility. There are 12 NVA activities, all obviously from transportation and storage, out of 17 in total. Therefore, a main objective for further analysis of this paper is to eliminate or, at least, reduce both *time spent in storage* and *distance traveled within the production plant*. To do that, Olhager (2013) for example suggests changing the layout or eliminate process steps all together if possible. Other solutions to reduce *time in storage* involve better planning and synchronization (Olhager, 2013).

Moreover, inspection is seen as an ENVA activity since it is needed after every VA activity to maintain good quality, but the inspection itself does not add any value. If possible, the ultimate goal is to reduce time spent on inspection as well. However, this paper does not provide any further investigation into that due to time limitations.

A summary of the current state at TePe is illustrated in *Table 4.2* below.

Table 4.2. Metrics for current state based on high volume products, from the VSM and operations chart.

Area	*Metric*	*Current state*	*Projected future state*	*Projected % improvement*
Efficiency (RQ1)	Total lead time	31 weeks	–	–
	Total process time	23.75 min	–	–
	Activity ratio	0.03 %	–	–
Safety (RQ2)	Distance traveled	295.5 m	–	–
Quality	Rolled % complete & accurate	97.4 %	–	–

4.6 Challenges

TePe faces several challenges in their production facility. Many of the challenges are first detected through direct observations, since genchi genbutsu is extensively applied in this paper. Other challenges arise from interviews with either operators or management. To find root causes to all challenges, *Ishikawa diagrams* are established for the majority of RQs. Since the root cause can originate from another area than in which the problem first arises (Olhager, 2013), all challenges either mentioned in interviews or observations are taken into consideration even though they are not clearly related to materials supply processes. Olhager (2013) emphasizes the importance of questioning the obvious reason of the first problem using *enough* whys for the root cause to emerge. Therefore, this paper uses what I evaluate being an enough amount of whys in regards to specific problems. In interviews, for example, more obvious reasons/whys are not asked for, but instead they are composed in a brainstorming session after each interview. For the brainstorming process as well as challenges mentioned only by employees and their own suggestions on improvements, see *Appendix XIII*. Challenges related to each RQ are further discussed.[22]

4.6.1 Efficiency

Based on the VSM, the current activity ratio is below the *"0.05 to 5 per cent rule"*. This is seen as the main challenge at this point in time, and therefore, the first Ishikawa diagram (fishbone diagram) is established to find root causes to long LTs and WTs. All challenges in *Figure 4.8* seem worthwhile investigating, even though those presented closest to the main bone are seen as root causes to challenges presented closer to the Ms.

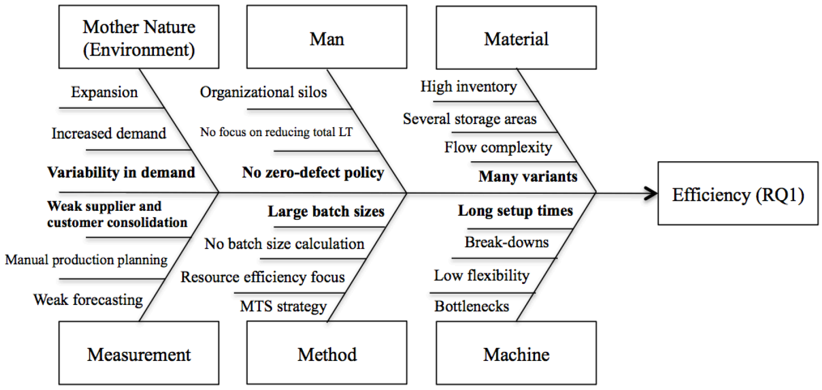

Figure 4.8. Ishikawa diagram to find root causes related to efficiency.

There are six root causes found related to flow efficiency. Those are linked to (1) variability in demand, (2) supplier/customer consolidation, (3) defect policy, (4) batch sizes, (5) number of products and (6) setup times.

Based on sales volumes and results from an earlier consulting job, there is a *variability in demand* at TePe. From week to week, there can be a 100 per cent difference in sales volumes. For example, one week there are products delivered with a value of two million SEK, whereas next week that same value is four million SEK. This, in turn, requires a high flexibility in the production facility. This challenge is probably closely related to the second root cause, namely: *weak supplier and customer collaboration*. According to TPS/Lean, an ultimate aim is that companies collaborate with their suppliers and customers to reach jointly set objectives and integrate their supply chains. That TePe has a manually planned production based on production planner's experience is another challenge closely related to previously mentioned root causes.[23]

[22] The majority of root causes are validated by key employees at the company.
[23] However, all three challenges are topics for future research since they are not part of the scope of this paper.

The third root cause is that TePe does not have a *zero-defect policy*. During observations, I recognized a mass-producing mentality among the workforce, which is not in line with the TPS/Lean mentality of striving for zero defects. Especially in injection moulding, there could be a few hundred products piling up on the floor beneath a machine, because of a transportation box not being in place. Adding a high number of defects after a machine changeover makes it difficult to anticipate output from each operation. Moreover, based on observations, there seems to be a risk of scrapped SKUs in mixing due to overturned transportation boxes. Reasons for this can, for example, be a stressful environment or poor education.

The fourth root cause based on the Ishikawa diagram is the non-existing method for calculating *batch sizes*. When the safety stock drops beneath the 10 per cent limit of the product's annual demand, the planners initiate a production order based on experience. Moreover, the number of SKUs on each pallet from injection moulding does differ between 8 500, 14 400 and 19 008 pcs. HVPs are more often produced in high volumes while LVPs are produced in low volumes. However, not having a clear way of calculating batch sizes leads to high WIP levels. This challenge springs from a make-to-stock mentality and resource efficiency thinking.

The fifth root cause is the *many variants* of products, colors and packages at TePe. Adding both raw materials and semi-manufactured products, there are more than 217 unique SKUs for toothbrushes. For example, there are 51 unique packages for different products in various languages[24] and 26 unique types of filaments. This leads to a complex flow of materials, leading to high safety stock margins, which generates a high number of SKUs in inventory. For example, TePe needs to build up a buffer of handles in different colors in intermediate storage prior to mixing due to a batch in a single color taking several days to finish in injection moulding. In other words, there is congestion in the area between injection moulding and mixing. Sometimes, the assembly/packaging operators even has to pick up a few boxes of missing colors from a non-finished batch in injection moulding. Based on several interviews, injection moulding can be a bottleneck as well.

Finally, the last root cause is long setup times. Since there is a broad product portfolio, many changeovers are needed. In turn, this affects the lead times and impedes the flow of products. Another identified issue related to setup times is the unnecessary time spent on searching for shared tools among departments. TPS/Lean encourages standardized work procedures and 5S to deal with such problems.

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[24] Internally, they are called "blisterbaksida" in Swedish.

4.6.2 Safety

Based on RQ2, an Ishikawa diagram is established to search for root causes related to safety challenges found. The root causes are presented in *Figure 4.9*, and relate to (1) resource efficiency, (2) safety measurements, (3) asset conditions, (4) replenishment procedures, (5) materials accessibility and (6) area restrictions and painted lines.

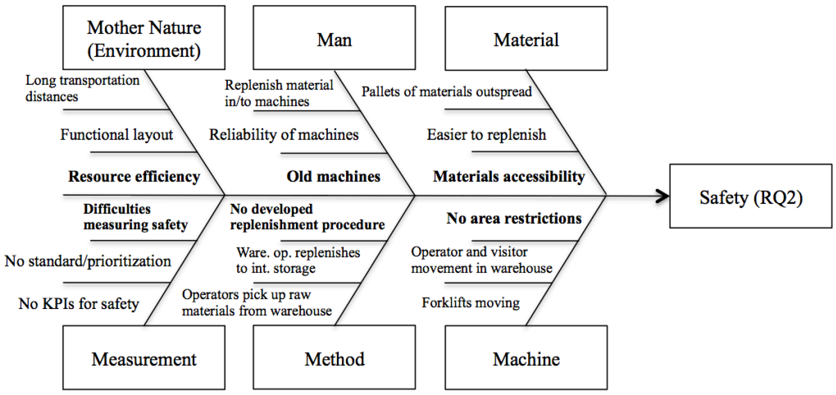

Figure 4.9. Ishikawa diagram to find root causes related to safety.

The first root cause is part of the mass-producing mentality at the company: *resource efficiency*. Mostly due to automation, TePe has become a company with, what Modig and Åhlström (2012) would call, efficient islands. This leads to several secondary needs (see *Chapter 2.18*). An organization also needs to focus on flow efficiency to reduce superfluous work and eliminate wastes.

The second root cause is *safety measurements*. Today, TePe does have a zero tolerance towards serious accidents. However, they lack in having an organized way of finding incidents and observing risks among operators.[25] Moreover, some deterioration in *asset conditions* also impact safety, but resource efficiency and number of defects as well.[26]

The fourth *(i.e. replenishment procedure)* and fifth root cause *(i.e. materials accessibility)* are closely related to each other. Operators are forced to pick up raw materials and semi-manufactured products in intermediate storage (TEPE3). This obviously increases safety hazards, since forklifts move there. There are also raw materials spread out within the assembly/packaging area (PROD3), which means forklifts and operators working side-by-side there as well.

Lastly, the sixth root cause targets *area restrictions*. There are no restricted areas for visitors or operators in neither intermediate storage (TEPE3) nor RMW/FGW (TEPE2). There are, however, painted lines in assembly/packaging today.

[25] FMEA analyses are used annually in each department by management, yet not among the operators.
[26] The machine park is, however, not part of this paper's scope.

4.6.3 New production facility

Since the transfer to a new production facility is a future event, it is prepostreous to try finding root causes to challenges related to RQ3. However, some possible challenges have been raised during interviews regarding the materials supply processes in the new production facility. Those are primarily related to *(1) an elevator* and *(2) storage*.

In the process of transfering their production of toothbrushes to another greater facility, which is in line with their expansion objectives, TePe has built a new facility, however, divided into two different floors. The only connection between the two is an elevator, in which all raw materials, semi-manufactured products and finished goods shall pass. A few employees share the worry of the elevator being a bottleneck in the system.

The other main challenge has to do with the storage of raw materials in the new production facility. There is, for example, no paternoster lift in the new facility. The question is where to store articles that are either assigned today's lift (TLIFT) or fixed pallet positions in TEPE3 or PROD3.

4.6.5 Prioritized challenges

Based on this within-case analysis, the majority of abovementioned root causes seems possible to mitigate by implementing specific TPS/Lean constructs. The prioritized challenges, being part of this paper's scope, is presented in *Table 4.3*, together with possible TPS/Lean constructs to mitigate them. Each root cause has a reference to its research question in parenthesis.

Table 4.3. Prioritized root causes and possible constructs.

Prioritized root causes (see Chapter 4.6)	***Possible constructs (see Chapter 7)***
Uncertainties with bottlenecks (3)	7.1 Bottleneck identification and elimination
Many product variants (1)	
Long setup times (1)	7.2 Setup time and batch size reduction
Large batch sizes (1)	
Much tied-up capital (1)	
Low flow efficiency (1)	
Simultaneous movement of operators and forklifts (2)	7.4.1 Relocation of mixing
Area restrictions (2)	
Materials accessibility (2)	7.4.2 Supermarket
Storage (3)	
Replenishment procedure (2)	7.5 Kanban
Materials visibility (1)	
Much tied-up capital (1)	
Time spent on non-value added activities (1)	7.6 5S
Safety challenges (2)	

Chapter 5. TPS/Lean Implementation: Case Descriptions and Analyses

This chapter describes and analyzes empirical findings from each case company: TePe, a company not using TPS/Lean principles to a great extent and Nolato, publicly noticed for using Lean. Each case company are presented through the following aspects: strategy, characteristics, implementation of TPS/Lean principles, critical success factors and challenges. This paper's TPS/Lean maturity model is used for a comparison between the companies. Nolato recommendations conclude the chapter. The entire chapter works as the foundation of the following cross-case analysis in Chapter 6.

5.1 TePe Munhygienprodukter AB

TePe have their headquarters in Malmö, Sweden, and they are the parent company to subsidiaries worldwide, in: Australia, the Benelux countries, France, Germany, Italy, Scandinavia, United Kingdom and USA (TePe f). There are basically four major departments at the parent company, which is illustrated in *Figure 5.1* (TePe f).

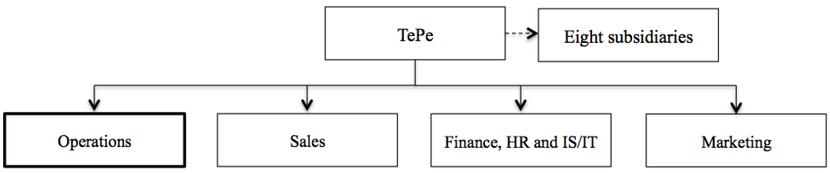

Figure 5.1. Departments at TePe.

5.1.1 Strategy

TePe have all their development and production in Malmö, Sweden, giving them transparency and flexibility (TePe g). They strive for resource efficiency by having their production site in Malmö automated. They also have the endeavor to reach eight strategic success factors in (1) made in Sweden, (2) the TePe brand, (3) quality, (4) innovation, (5) partnership, (6) organisational set-up, (7) people & competence and (8) new technology. Moreover, an integral part of TePe's work is based on sustainability (TePe g), and they apply eight out of 17 goals from United Nation's Sustainability Development Goals (SDG).[27] In Malmö today, TePe uses the *Overall Equipment Effectiveness (OEE)* as their KPI in production. Through this KPI, they understand how well their manufacturing operations perform in terms of availability, performance and quality. Moreover,

[27] SDG is a set of urgent global goals designed to be achieved prior to 2030.

TePe uses KPIs such as (1) number of products manufactured, (2) defect ratio, (3) customer delivery precision, (4) stock availability and (5) stock value. Efficiency is not the only aspects TePe strives to enhance in the future, and, therefore, this paper's research combines efficiency with another important aspect: safety. Finally, TePe applies a manufacture-to-stock (MTS) policy within their production facility.

5.1.2 Characteristics

A detailed description of the operations within the production facility at TePe is presented in *Chapter 4.4*. For a more in-depth description of the overall characteristics based on visual mapping techniques, *Chapter 4.5* is suggested.

5.1.2.1 Efficiency (RQ1).

To analyze TePe's profitability and asset efficiency, a Du Pont model is presented in *Figure 5.2.* The analysis shows that they rely heavily on the operating profit margin, which basically means that they have high sales in relation to expenses and net sales revenue.

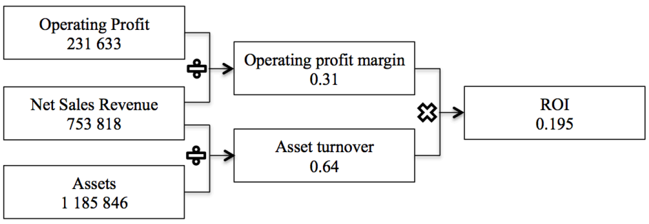

Figure 5.2. Du Pont analysis of TePe 2018 (TePe h).

TePe's asset turnover has, in fact, decreased with 28 per cent over a twelve-year period (TePe h), which indicates that the company uses their assets more poorly today than before. On the contrary, they have increased their operating profit margin with 41 per cent over the same period. Both trends are illustrated in *Figure 5.3* below. The ROI has not changed over the twelve-year period.

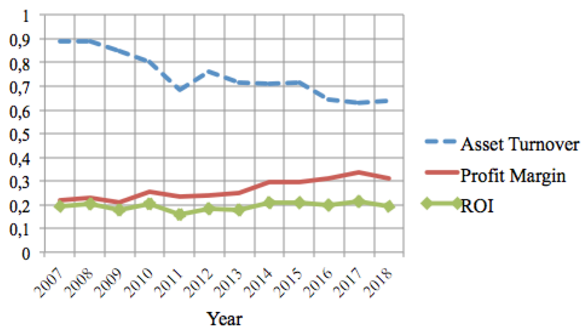

Figure 5.3. Trends of asset turnover and profit margin from the Du Pont analysis (TePe).

5.1.2.2 Safety (RQ2).

Work environment management, employees and safety are all important aspects at TePe. All work needs to be conducted in a structured and secure manner to reach the zero accident goal (TePe g). Therefore, the majority of machines have safety equipment. To reduce risk of injuries or ill health, all operations undergo risk analysis, such as FMEA[28], annually or in modification phases (TePe g). There are also four safety inspections yearly, in which attendance, accident and injury statistics are evaluated (TePe g). However, processes in-between operations, such as supplying materials do lack in safety regulations, according to TePe employees. For more details, see safety challenges in *Chapter 4.6.2*.

5.1.3 Implementation of Lean principles

The implementation of different TPS/Lean principles, and their methods, at TePe is presented in *Table 5.1*. The principles are based on the theoretical framework, summarized in *Chapter 2.1*, and the evaluation is based on the TPS/Lean maturity model established in *Chapter 2.19.2*, and, again, presented to the reader in *Figure 5.4* below. Brief explanations to each assessment follow.[29]

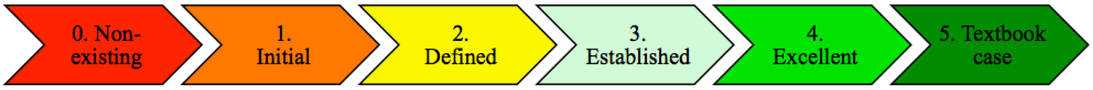

Figure 5.4. Stages in the TPS/Lean maturity model.

[28] *Failure Mode and Effects Analysis* is a structured approach of identifying failures, and their effects, within a design of a process or products. The aim of a FMEA is to identify, prioritize and limit the failure modes.
[29] The assessment based on the TPS/Lean maturity model is roughly validated by a key employee at TePe.

Table 5.1. Implementation of TPS/Lean principles and methods at TePe today.

Principles	***Methods***	***Stage***
Jidoka	Genchi Genbutsu	2
	Poka-Yoke	4
	Andon	4
	5 Whys	1
	5S	0
Just-in-Time	Takt Time	0
	Continuous Flow	0
	One-Piece Flow	0
	Pull	0
	Kanban	1
	SMED	0
People & Teamwork		4
Heijunka		0
Standardized Work		3
Visual Management		3
Kaizen		2
Other Lean Tools	Value Stream Mapping	0
	Ishikawa	2
	Product Family Matrix	0
	Pareto Chart	3

5.1.3.1 Genchi genbutsu.

Management are aware that observing the actual site where work takes place is the best thing to do to understand problems. The method, however, is applied sparsely. Interviews with operators verify the case. The method is assessed as defined.

5.1.3.2 Poka-yoke.

A process is stopped immediately if something happens. There are mistake-proofing methods built-in automatically in the machine. TePe do work with autonomation, since operators shut down the machines if something is wrong, then, tries to fix the problem at least in the short-term. The method is assessed as excellent.

5.1.3.3 Andon.

The machines also have in-built signals for processing (green) and not processing (red). The signals are activated automatically by the machines, and are shown all over the production facility. The method is assessed as excellent.

5.1.3.4 5 Whys.

In the production facility, root cause analyses are often not performed by any operators. They, instead, try to solve the issue at hand quickly to start up the production again. The method is assessed as initial.

5.1.3.5 5S.

In the production area, TePe does have floor markings for materials close to the machines. However, they lack in aspects such as (1) every-day cleaning and (2) tools not being ordered in close proximity to operations. Basically, they have not implemented 5S. The method is assessed as non-existing.

5.1.3.6 Just-in-time.

TePe does not work with any of the methods under the principle JIT. However, they have started discussing an implementation of Kanban, and use an elementary Kanban design without any WIP limits today. Kanban is assessed as initial, whereas all the other methods are assessed as non-existing.

5.1.3.7 People & teamwork.

In production, operators are responsible for different machines. However, if there are breakdowns or something unexpected happens, they help each other out. This is important for TePe, and therefore they educate their employees in such manners. Employees are also educated in leadership and teamwork, with the basis of supporting a sound culture (TePe g). Moreover, weekly meetings are held in production to highlight issues and news. There are also manager meetings on the floor, in which aspects such as (1) targets and (2) actual production output is updated daily. I have, however, experienced challenges in department collaboration, and, at times, an *”us-versus-them”* mentality between operators and management. The principle is still assessed as excellent.

5.1.3.8 Heijunka.

The demand is highly variable, and so is the production. The production planning is based on annual demand and current inventory levels. There is no production smoothing. The principle is assessed as non-existing.

5.1.3.9 Standardized work.

The operations contain standardized procedures to follow at TePe performed by employees. However, there is often not any standardized documentation on how an operation should be carried out. For example, there is no documentation on how a machine setup should be performed. This, in turn, leads to difficulties in making use of continuous improvements of the operation over time. Neither is there any standardized way of training operators to follow a zero defect policy, which, at times, causes carelessness among personnel. However, the principle is assessed as established.

5.1.3.10 Visual management.

TePe makes use of a whiteboard to display targets and actual production output for each production area. Incidents and risk observations are also highlighted visually, and unstructured pictures of how a clean work environment should look like are displayed. The principle is assessed as established.

5.1.3.11 Kaizen.

TePe puts effort in continuous improvements, especially in the area of sustainability where the SDGs are followed (TePe g). They work with constant improvements in environmental and quality efforts in accorance with ISO 14001 and ISO 9001 (TePe g). However, they lack in standardized kaizen procedures on the floor, which emphasizes the behaviour of operators solving problems in the short-term rather than permanently. The principle is assessed as defined.

5.1.3.12 Other Lean tools.

Management does work with Ishikawa diagram analyses and Pareto charts. However, value streams are not a focal point, and they lack in the use of such methods.

5.1.4 Success factors

TePe utilizes a totally automated machine park, giving them the opportunity to manufacture toothbrushes around the clock. They, therefore, have a competitive advantage with an immense profit margin, since the manufacturing costs of a toothbrush is relatively low. This enables TePe to keep their production in Sweden with sound and safe work enviroments (TePe g). Therefore, focus has been put on TPS/Lean tools such as *poka-yoke* and *andon*, to enhance a more efficient work environment. Other TPS/Lean success factors are *people & teamwork*, which builds a culture of belongingness.

5.1.5 Challenges

TePe meets challenges in several areas. Challenges based on (1) efficiency, (2) safety and (3) new production facility are presented in more depth in *Chapter 4.6*, as well as *Chapter 6.2.4*.

5.2. Nolato MediTech

Nolato is a Swedish publicly listed group having operations in Europe, North America and Asia (Nolato, 2018). Nolato's business consists of developing and manufacturing polymer materials such as plastic, silicone and TPE, i.e. thermoplastic elastomer. Their customers are found in industries such as medical technology, pharmaceuticals, automotive, telecom and customer electronics (Nolato a). The company was founded in 1938 as Nordiska Latexfabriken i Torekov AB, but changed their name to the abbreviated version *Nolato* in 1982 (Nolato, 2018). Their headquarters remain in Torekov, Sweden, today employing 6 400 people world-wide (Nolato, 2018). In the fiscal year of 2018, Nolato generated net sales of around 8.1 billion SEK (Nolato, 2018).

Nolato is further divided into three business areas: (1) Medical Solutions, (2) Integrated Solutions and (3) Industrial Solutions. Nolato MediTech is part of Medical Solutions, and is situated in Hörby, Sweden. The structure of Nolato's business areas is simplified in *Figure 5.5* below.

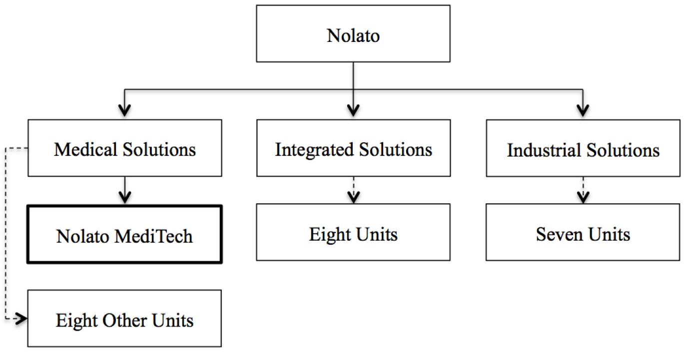

Figure 5.5. Structure of Nolato's business areas.

Nolato Medical Solutions both develops and manufactures components and product systems within medical technology, and also packaging solutions for pharmaceuticals and dietary supplements (Nolato, 2018). They have a few standard products in some areas, such as pharmaceutical packaging but products are primarily customer-driven (Nolato b).

5.2.1 Strategy

Nolato has some basic principles, namely: (1) customer focus, (2) decentralization, (3) innovative thinking, (4) knowledge, (5) social responsibility and (6) sustainable development (Nolato c). They also want to be regarded as the customer's first choice and always strives for exceeding customer expectations (Nolato d). Key factors in achieving their vision of being *One Nolato* are for example long-term customer relationships, broad customer offerings and high productivity (Nolato d). *"Lean Manufacturing helps … [them] maximise business benefit, streamline processes, reduce scrap, cut lead times and develop innovative solutions"* (Nolato d). Nolato also has a clear customer-driven strategy of making products to order (MTO).

Many companies today work with company-specific programs to seek improvement. They are often called XPS (i.e. [Company name] production system), inspired by the Toyota production system (Olhager, 2013). Nolato MediTech uses *Medical Excellence (ME)* in their way of creating "*world-class operations"*. ME is based on the company's values and Lean processes, and, then, developed specifically to fit the medical technology and pharmaceutical sector (Nolato c). ME was developed at Nolato's production site in Hörby, Sweden, and consists of eight elements (*Figure 5.6*), which form a framework for increasing customer-value and managing resources efficiently (Nolato c). The objective is to supply high-quality products on time with minimal waste. If customer's expectations are exceeded, a continued excellence can be guaranteed as a long-term competitive edge for both Nolato and their customers (Nolato c).

At their site in Hörby, Nolato has four strategic objectives in (1) efficiency, (2) quality, (3) safety/environment and (4) service (Danielsen, personal communication, January 30, 2020)[30]. To be able to meet the objectives, they have ten KPIs that are evaluated regularly. They measure efficiency through *OEE, scrap* and *inventory days,* quality through *customer claims, complaints, audit remarks* and *supplier quality*, safety/environment through *accidents,* and service through *customer delivery precision* and *supplier delivery performance*.

Figure 5.6. Nolato Medical Solutions' production system and its eight values (Nolato c).

5.2.2 Characteristics

The majority of Nolato's products go through a similar sequence, containing injection moulding, hardening, assembly and packaging. Products are stored in-between processes, but no more than a day to a week. Lead times of their products can vary from a week to a couple of months, but mostly, for their A-classified products, there is a lead time of four to five weeks. Order sizes are no more than one week of production, however, batch sizes are multiples of 4000 pieces to increase flexibility in production. This is based on forecasts of yearly demand, which Nolato recieves from customers. They have a close collaboration through, for example, VMIs for regular updates on inventory levels. The actual amount of tied-up capital are, however, classified information, but, what can be said is that, Nolato always strives to decreasing their inventory.

[30]Data without references in the following paragraphs are either based on a half-day observation of Nolato MediTech's production site or a single interview with Lean coordinator Lennart Danielsen, who later has verified the outcome. Danielsen has eight years of experience in his position, but has been an employee of the company since the 1980s.

5.2.2.1 Efficiency (RQ1).

Nolato MediTech started implementing Lean in 2010. Over the decade, the productivity has increased with more than 65 per cent. A Du Pont analysis is conducted to understand Nolato's profitability and asset efficiency (see *Figure 5.7*). A high asset turnover shows that the company today relies on their internal efficiency rather than their profit margin.

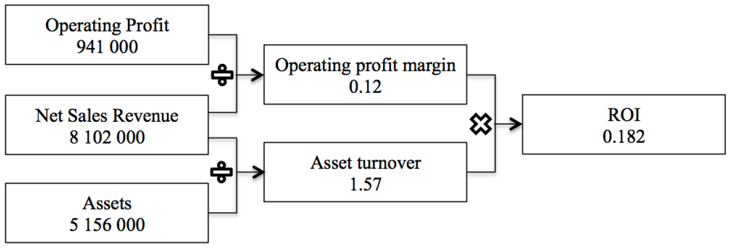

Figure 5.7. Du Pont analysis of Nolato. Based on Nolato (2019).

Nolato's asset turnover has, in fact, increased since their Lean implementation. Over the last twelve-year period, it has increased with 24 per cent (Nolato, 2019), indicating that the company uses their assets more efficient today than before. They have also increased their operating profit margin slightly. Both trends are illustrated in *Figure 5.8* below. The ROI has doubled over the twelve-year period.

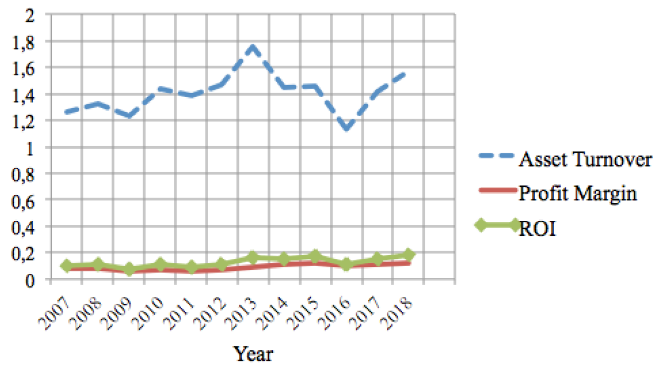

Figure 5.8. Trends of asset turnover and profit margin fron the Du Pont analysis (Nolato).

5.2.2.2 Safety (RQ2).

Safety is always the number one priority for Nolato. They strive for a zero-accident environment, and no serious accidents[31] have occured since the Lean implementation. The company measures four variables based on the KPI of accidents. There are (1) number of accidents, (2) incidents, (3) risk observations and (4) environmental deviations. The measures are well established over the facility. Management appreciates a high number of risk observations to continuously strive for

[31] An employee being on sick leave for at least one day.

improvements. To further prevent safety hazards, they also apply different methods such as the safety cross and well-ergonomic work environments for employees, as well as the *Occupational Health and Safety Assessment Series 18001*.

5.2.2.3 Extra characteristics.

The customers of Nolato require manufacturing processes being in cleanrooms. Cleanrooms are, basically, rooms that minimize the introduction, generation and retention of particles (Whyte, 2004). The International Organisation for Standards (ISO) has developed nine ISO class standards containing a wide variety of cleanliness aspects, such as design, operations, testing and biocontamination (Whyte, 2004) to maintain extremely low levels of particals, including dust, vaporized particles and airborne organisms. Cleanrooms are used extensively in the industry of pharmaceuticals and medical devices. At Nolato, there are regular particle measures and biological sampling of their operations. Nolato operations require the second lowest standard: ISO Class 8. They use special clothing in production that envelopes the employee and trap contaminants naturally generated by skin and body, i.e. cleanroom suits (Whyte, 2004). The cleanrooms are entered and exited through airlocks. Each product are then packed into a plastic packaging in the cleanroom, before it is transported in a sealed secondary package to the warehouse.

5.2.3 Implementation of Lean principles

The implementation of different TPS/Lean principles, and their methods, at Nolato MediTech is presented in *Table 5.2*.[32] The principles are based on the theoretical framework, summarized in *Chapter 2.1*, and the evaluation is based on the TPS/Lean maturity model established in *Chapter 2.19.2*, and, again, presented to the reader in *Figure 5.9* below. Brief explanations to each assessment follow.

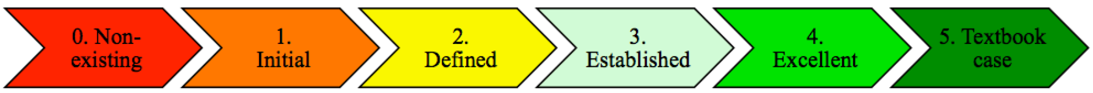

Figure 5.9. Stages in the TPS/Lean maturity model.

[32] Since Nolato MediTech has been implementing their production system ME based primarily on Lean initiatives, they are well versed in the area of TPS/Lean.

Table 5.2. Implementation of TPS/Lean principles and methods at Nolato MediTech today.

Principles	***Methods***	***Stage***					
Jidoka	Genchi Genbutsu	0	1	2	3	**4**	5
	Poka-Yoke	0	1	2	3	4	**5**
	Andon	0	1	2	3	4	**5**
	5 Whys	0	1	2	3	**4**	5
	5S	0	1	2	**3**	4	5
Just-in-Time	Takt Time	0	1	2	3	**4**	5
	Continuous Flow	0	1	2	**3**	4	5
	One-Piece Flow	**0**	1	2	3	4	5
	Pull	0	1	2	**3**	4	5
	Kanban	0	1	**2**	3	4	5
	SMED	0	**1**	2	3	4	5
People & Teamwork	–	0	1	2	3	4	**5**
Heijunka	–	0	**1**	2	3	4	5
Standardized Work	–	0	1	2	3	**4**	5
Visual Management	–	0	1	2	3	4	**5**
Kaizen	–	0	1	2	3	4	**5**
Other Lean Tools	Value Stream Mapping	0	**1**	2	3	4	5
	Ishikawa	0	1	2	3	**4**	5
	Product Family Matrix	0	1	**2**	3	4	5
	Pareto Chart	0	1	2	3	4	**5**

5.2.3.1 Genchi genbutsu.

Management strives for *genchi genbutsu* as much as possible. Every morning there is a pulse meeting on the floor at each department. Since Nolato has their injection moulding, hardening and assembly processes in clean rooms, genchi genbutsu is a challenge for management. But there are windows all around the facility to ease transparency. The method is assessed as excellent.

5.2.3.2 Poka-yoke.

A process is stopped immediately if something happens. There are mistake-proofing methods built-in automatically in the machine. This includes leak testing within the machines. Moreover, Nolato always work with autonomation, since operators shut down the machines if something is wrong and, then, tries to fix the problem and understand the root causes. The method is assessed as a textbook case.

5.2.3.3 Andon.

The machines also have in-built signals for (1) processing (green), (2) detected problem or full secondary package (orange) and (3) not processing (red). The signals are activated automatically by the machines, and are shown all over the production facility. The method is assessed as a textbook case.

5.2.3.4 5 Whys.

Both management and operators are educated in simple Lean methods such as *5 Whys*, and is taught that the problem at hand is often not the root cause. This method is used by the management often, especially in the process of evaluating deviations. The method is assessed as excellent.

5.2.3.5 5S.

Nolato has not implemented *5S* per se, but do use the method. They have specific areas for tools (Sort) and floor markings for both equipment and for non-operators within the warehouse (Set in order) to increase workflow and safety, respectively. Moreover, there are requirements on a clean work environment since Nolato work in the medical business (Shine). They also work a lot with education and training sessions for employees to understand Lean (Sustain). The method is assessed as established.

5.2.3.6 Takt time.

Nolato is totally aware of takt times and cycle times for their production. Their production is, according to Danielsen (personal communication, January 30, 2020) *”strongly validated by customers”*. At times, production is stopped, since a pull system between processes is used. When there is nothing to produce, the machines can be idle. The method is assessed as excellent.

5.2.3.7 Continuous flow.

Nolato is aware of the importance of striving for a continuous flow, and implements the method as far as possible. They use several tools to accomplish a continuous flow. For example, they try to minimize batch sizes as much as possible, which leads to less WIP, a lower amount of inventory and, finally, a better flow. Order sizes can vary quite a lot (~10 000 – 1 000 000 pcs), but Nolato use batch sizes in multiples of 4000 pcs. The maximum multiple is three, which means that there can never be more than 12 000 pcs as WIP. Batches are partly customer-driven, but there are other aspects to them as well, such as in-process controls based on quality requirements from customers[33] and efficiency parameters in transportation affecting batch sizes. Therefore, they cannot be calculated with any specific formula. The standard rule for batch sizes at Nolato, however, is that they are restricted to a maximum of one week of demand. Moreover, they use pull systems (see *Chapter 5.2.3.9* below) over the production facility to enhance a contionuous flow. The method is assessed as established.

5.2.3.8 One-piece flow.

Nolato has not implemented any one-piece flow of products. Lennartsen (personal communication, January 30, 2020) emphasizes that a one-piece flow is the optimal solution in theory, but hard to implement in practice. The method is assessed as non-existing.

5.2.3.9 Pull system.

As mentioned above, a visual pull system is partly used in-between processes to avoid overproduction and other wastes. Especially has this been implemented between injection moulding and assembly, where the injection moulding processes at times stay idle for assembly to finish its production. The method is assessed as established.

[33] For example, increased *measurement frequency* leads to more documentation.

5.2.3.10 Kanban.

Nolato have implemented the pull system into other parts of the system as well. They use what Danielsen (personal communicaton, 30 January, 2020) calls a ”*business-like kanban”* for around five per cent of their warehouse. There are no kanban cards involved; rather is the replenishment a visual process of empty stock locations. As part of this kanban system are high volume products. They have specific stock locations within the warehouse. When a location is empty, a production order is initiated. In addition, Nolato use vendor managed inventory (VMI) to increase integration over the supply chain. They share their inventory data with customers to, for example, decrease bullwhip effects in the supply chain. Together with their customers, they have established minimum and maximum values for the amount of specific products stored in inventory. In this sense, Nolato implements a customer-driven production. The method is assessed as defined.

5.2.3.11 SMED.

Nolato has not yet prioritized a reduction of setup times. After assessing the value stream, Nolato decided to focus on increased quality by a reduction of defects, rather than implementing *SMED*. However, their setup times are approximately two hours, and according to literature (see Yamashina, 1982; Shingo, 1984; Olhager, 2013), there would be beneficial to reduce them. The method is assessed as initial.

5.2.3.12 People and teamwork.

At every level, and for every department, stand-up pulse meetings are used every day in front of three different white boards based on (1) objectives, (2) pulse and (3) continuous improvement (CI). They are all synchronized as *Figure 5.10* shows.

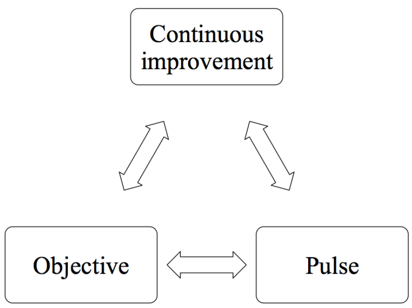

Figure 5.10. The basis of each pulse meeting.

The pulse board basically shows the pulse of the production, i.e. how well the production performs. *Targets* and *actual production output* is updated daily. The pulse is always related to the objectives of the company and their KPIs, as well as possible improvement areas through the CI board. If there is an improvement possiblity, it is always highlighted in a specific color based on the objectives. Pulse meetings are used throughout the company at different levels, as can be seen in *Figure 5.11*. This supports for people involvement and teamwork both between departments and between management and operators.

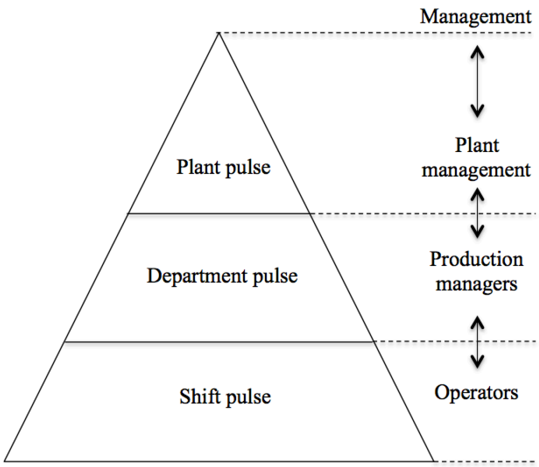

Figure 5.11. The structure of pulse meetings at different levels (left) of Nolato MediTech, including participants (right).

Nolato also works with plenty of training sessions and education in Lean for all their employees. For example, they have started a Medical Excellence Academy (see *Chapter 5.2.3.14* below). The principle is assessed as a textbook case.

5.2.3.13 Heijunka.

Nolato tries to leveling production out as far as possible. Tools, such as the Pareto chart, help them understanding important aspects of demand, such as volumes and mixes, to build a leveled schedule. However, since setup times are quite high, this cannot be implemented to its fullest potential. The principle is assessed as initial.

5.2.3.14 Standardized work.

Nolato works after the standardized quality management system for medical devices, ISO 13485. Moreover, through their new initiative *Medical Excellence Academy*, they work with an internationalized standardization over business units. This is used as both an eduction system for employees as well as a self-assessment tool on objective performances on all levels (tactical, operational and strategical). Internal comparison is also important, and they compare performances between business units. Each operation within the production is also a standardized procedure, which is followed by the employees. The principle is assessed as excellent.

5.2.3.15 Visual management.

Visual management is applied all over the facility, with the pulse meetings as foundation. Specific continuous improvements (CIs) are also visualized at whiteboards, as well as incentive systems for employees and KPI comparisons against other business units within Medical Solutions. The principle is assessed as a textbook case.

5.2.3.16 Kaizen.

Nolato puts a lot of effort into CIs. It can be everything from a very small improvement to something that requires more time and effort. Over the last five years, they have accompished around 5000 improvements, and an extra 5000 corrective and preventive actions. Every improvement is also logged for the future. The CIs often start through the pulse meetings, in which disturbances float up to the surface. The issue should, then, be solved in the short-term to the next pulse meeting. A CI team, later, investigates the issue to find improvements, which leads to new standards, based on the objectives of the firm. Moreover, Nolato are transparent with their customers and assess *customer inputs* to improve their business. The principle is assessed as a textbook case.

5.2.3.17 Other Lean tools.

Nolato has implemented Pareto charts to a wide extent, since everything can be traced to the 80/20 principle, according to Danielsen (personal communication, January 30, 2020). They also use *Ishikawa diagrams* and similar tools extensively for root cause detection. Another Lean tool that Nolato has investigated is the *Product family matrix*. However, their production plant has a functional layout, mainly due to the fact that some operations need cleanrooms while other does not, and, therefore, the method contributes little. Moreover, since the value streams are quite short, Danielsen (personal communication, January 30, 2020) states that *Value stream mapping* is, probably, an unnecessary tool.[34]

5.2.4 Success factors

Danielsen (personal communication, January 30, 2020) emphasizes that the most important success factor for Nolato MediTech is the mindset of management, rather than specific tools used. Everything starts with softer values such as *management commitment* and *people involvement* for the creation of change (Danielsen, personal communication, January 30, 2020). This is in line with many researchers (see e.g. Yin, 2003; Näslund 2013; Chaihan & Chauhan, 2019). Chauhan and

[34] This statement can, however, be argued.

Chauhan (2019) present research on specific actions most important when implementing Lean principles. In top, there are (1) establishing a sense of belongingness and (2) developing mutual faith. These values did build a strong foundation for Nolato to calmly strive for important aspects such as (1) reduction of waste and (2) shortened lead times. Other success factors for Nolato are the professionalism of employees and education in Lean principles and leadership, as well as an excellent focus on what really is important. By creating their own production system *Medical Excellence*, Nolato developed their own values which they needed to follow. The Lean methods used were all a response on the values from Medical Excellence. In summary, the whole package brought success to the company.

5.2.5 Challenges

Before implementing Lean, Nolato was facing several challenges. They needed to enhance both (1) the quality and (2) the customer delivery precision of their products, as well as (3) the long-term competitiveness of the company. By applying the Lean mindset, employees started what Danielsen (personal communication, January 30, 2020) calls *”waste hunting”*. The company, of course, looks for all seven wastes, but the focal point has been the waste of *defective products*. Issues also arose specifically in the waste of *waiting time, unnecessary transportation* and *unnecessary movement*. But these wastes are reduced today due to the implementation of Lean. When a company has reached a certain level of overall Lean implementation, however, some challenges become barriers for a company according to Danielsen (personal communication, January 30, 2020). There is, basically, more difficult to proceed with positive results at same pace due to a greater need for resources. Another barrier for Nolato is batch sizes, which cannot be reduced more than actual sizes, since a further reduction would lead to an increased number of *sample measures* to sustain a high quality to customers in the medical business. There is always a trade-off, and therefore, it is important to find an optimal solution customized for the company in question.

5.2.6 Nolato MediTech recommendations and journey

Many authors suggest simple methods, such as *5S* or striving for *continuous flow*, for companies that are starting to implement Lean principles (see Al-Aomar, 2011, Liker, 2008). Danielsen (personal communication, January 30, 2020), however, does not recommend to start with tools alike; instead, understanding and spelling out the objectives of the company are much more important. Pulse meetings are, then, great to sustain the efforts. Danielsen (personal communication, January 30, 2020) emphasizes that an understanding of how *throughput times* really have an impact on a company is crucial as well. This goes down to educating employees all over the company.

The implementation process of Lean principles at Nolato has a lot in common with the findings of a cross-case study conducted by Yin (2003, pp. 144-163) on 14 American firms after a transformation process. There is a *motivation for change* at the outset (Yin, 2003). For Nolato, there were some *product quality issues* and deficiencies in *customer delivery precision*. There was also a need for productivity improvements (Yin, 2003), and the organization met challenges in basically every element of the seven wastes.

To remain competitive, Nolato searched for a well-established change initiative and found Lean. The Managing Director at the time, Johan Iveberg, was the driving force of implementing Lean in 2010. Yin (2003) states that the implementation of a change initiative often starts with the CEO pursuing a strategic plan, and a unitary vision and culture. This creates broad goals for the whole firm, such as continuous improvement, environmental efficiency and a customer-driven production (Yin, 2003). For Nolato, this process of evaluating their strategy resulted in the new production system Medical Excellence. Throughout the process, management were supportive in the transformation, which several researchers specify as the most important aspect in any change initiative (see e.g. Yin, 2003; Näslund, 2013; Chauhan & Chauhan, 2019). For Nolato, this meant that management were *knowledgable*, *participant-friendly* and *professional*, to mention a few. They also decentralized responsibilities onto the shop floor (Yin, 2003) through *pulse meetings* and *improvement teams* for each department.

The change led to several improvements, both in the short-term and in the long run. Nolato were soon better aligned with their strategy (Yin, 2003), and employees were more involved. This led to many incremental improvements, decreased lead times and a reduction in customer claims. In the long run, the change initiative seems to have contributed to sales and profit growth, and all other issues that were found prior to implementation. Moreover, the transformation led to a Lean success recognition, which is difficult to measure in monetary terms. They received media attention, leading to plenty of study visits, which, of course, boost reputation. Over the period of transformation, Nolato also re-evaluated their business strategy regularly. This has recently led to new education initiatives within the company, through for example *Medical Excellence Academy*.

5.2.7 Lean implementation process at Nolato

The entire process of the Nolato Lean implementation can be illustrated as an overall framework. *Figure 5.12* presents this logic model, which has sequential elements with, potentially, causal relationships in-between. In other words, the first element is the cause, whereas the subsequent event is the effect. The objective of this paper building a logic model is that it can guide the implementation of any change (Yin, 2003). The model is based on *Chapter 5.2.6*.

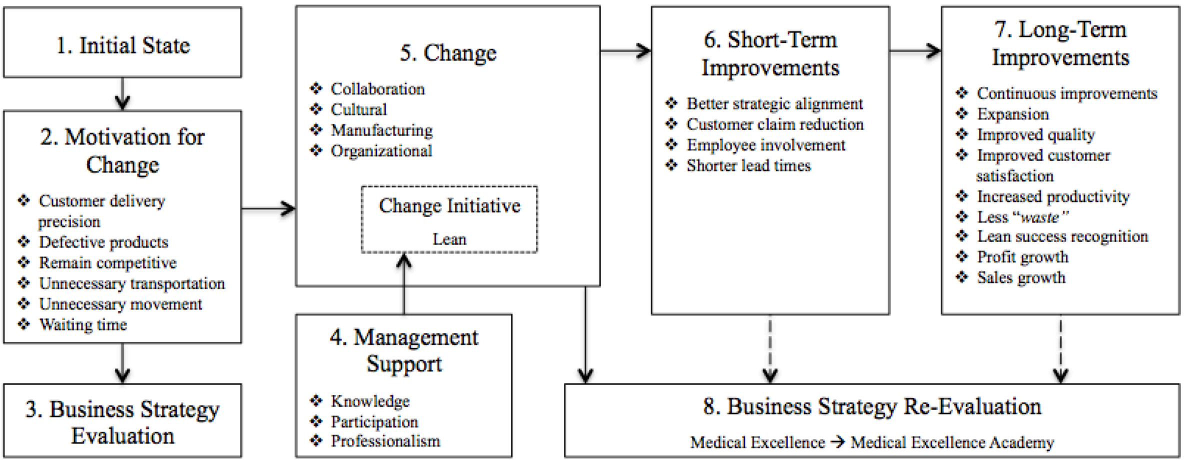

Figure 5.12. Lean implementation process at Nolato MediTech.

Chapter 6. Cross-Case Analysis

This chapter analyzes similarities and differences between the two case companies. Initially, there is a gap analysis comparing TePe's and Nolatos's current implementation of TPS/Lean principles, with an objective to understand how an implementation can affect the overall performance of a company. The strategies of both companies are, then, analyzed primarily based on efficiency, but also on safety. Prioritized challenges for TePe conclude the chapter.

6.1 Gap analysis

A gap analysis of the conceptually ordered matrices from previous chapter is presented in *Figure 6.1* to understand the differences between how well TePe and Nolato have implemented TPS/Lean principles and methods. Nolato serves as TePe's desired, or at least possible, degree of implementation. TPS/Lean principles, in *Figure 6.1*, are boldfaced and methods are normally printed. The gap analysis shows differences among almost every principle between the companies, and even remarkable differences in many. The principles of *jidoka, people and teamwork, standardized work, visual management* and *kaizen* stand out. Since this paper is, to some extent at least, based on subjective assessments of each TPS/Lean principle, there needs to be a (minimum) two-stage difference for the principle or method at hand for further inclusion in the cross-case analysis.

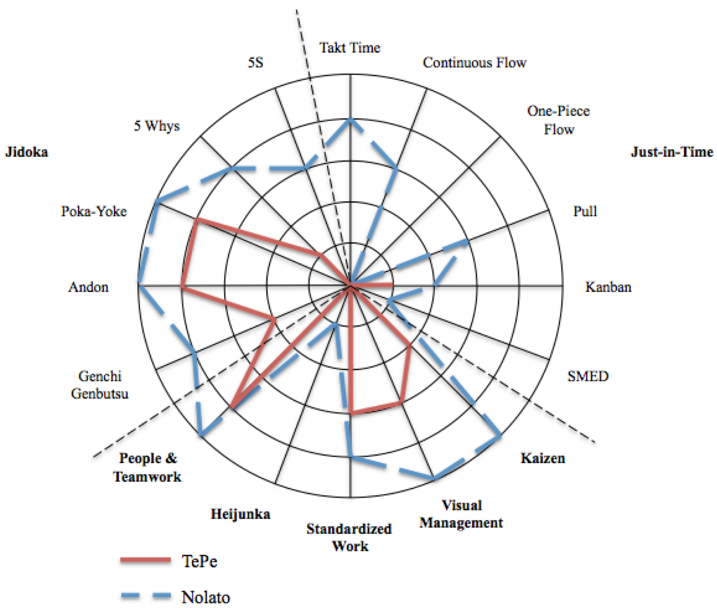

Figure 6.1. Gap analysis of the TPS/Lean implementation at TePe and Nolato MediTech based on the TPS/Lean maturity model.

The principles can roughly be divided into managerial principles and production principles. The principles differing most show a pattern of being mostly managerial (jidoka, people and teamwork, visual management and kaizen), while principles related to production (heijunka, just-in-time and standardized work) do not stand out in either company.

6.1.1 Managerial principles

Managerial principles are, in this paper, methods management or operators can use in the short-term to affect the performance of the company, such as collaborating, being present in production, applying continuous improvements, visually showing performance etc.[35] Principles included are (1) jidoka, (2) kaizen, (3) people and teamwork, (4) visual management. The most remarkable differences between TePe and Nolato are shown in these principles, even though these are the principles TePe actually has put work into already.

6.1.2 Production principles

Production principles are, in this paper, methods specifically related to hands-on production, which are used in the long-term to affect the performance of the company. Principles included are (1) heijunka, (2) just-in-time and (3) standardized work. But these differences are not as distinct as the managerial principles, even though TePe totally lacks in methods Nolato has established, such as use of takt time, continuous flow and a pull system.

6.2 Strategy

TePe and Nolato use similar strategies in many areas, but they also differ in their approach of these strategies. This paper further discusses similarities and differences in both strategies and implementation of principles between the companies based on two out of three research questions in more detail.

6.2.1 Efficiency

Both TePe and Nolato use similar strategies regarding automation of many operations. Both have the objective of being efficient in their production. However, Nolato is more Lean oriented and tries to focus not only on resource efficiency but on flow efficiency. These conclusions can be drawn from *Figure 6.2*, clearly visualizing how ROI has changed for both companies over the last decade.[36] Nolato has, since they introduced Lean in 2010, increased both asset turnover and

[35] In essence, all principles can be sorted into the category *managerial*, since management decides every final decision. However, this paper distinguish between categories based on time to implement a principle.

[36] The data shown is *Figure 6.2* has been received from *Chapter 5.2.3.1* and *Chapter 5.3.3.1*.

operating profit margin; increasing them in tandem is obviously the optimal goal. This has resulted in an increase of ROI from 9.8 per cent (2007) to 18.2 per cent (2018). TePe, however, has only increased their operating profit margin, but widely instead. In theory, they can continue increasing their profit margin forever without being much more profitable. Their ROI is practically unchanged; it was 19.6 in 2007 and 19.5 in 2018.

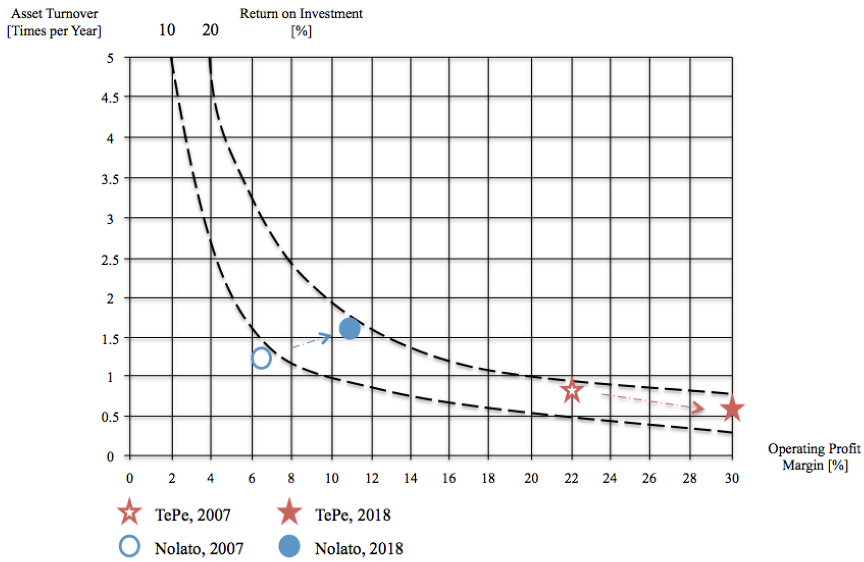

Figure 6.2. Du Pont analysis of each case company's ROI.

The results from the Du Pont analysis can have several different explanations, and a deeper investigation into both companies' entire organization may be needed to be completely certain in answering why these differences appear. This is not an investigation fitting the time frame of a Master's thesis. The results, however suggest that Nolato has a healthier relationship between departments, such as between operations and sales/marketing, with better aligned strategic objectives. The results also suggest that managerial TPS/Lean principles have a great impact on asset turnover, and in turn, profitability. Therefore, it is important for TePe to achieve a cultural change to reach their profitabilty objective of a 10-20 per cent organic growth yearly. Production principles do, of course, also affect asset turnovers, but the conclusion drawn from the assessment in *Figure 6.1* is that managerial principles have a greater impact, since these principles differ more between the companies. The focal point for TePe should, therefore, be to implementing and sustaining methods such as (1) genchi genbutsu, (2) visual management, (3) kaizen and (4) 5 whys, but also (5) 5S.

6.2.2 Safety

TePe and Nolato have the same objective of building a zero-accident environment. TePe measures three variables four times a year. Nolato, however, has implemented four continuously updated variables, KPIs, to reach the goal. None of the companies have had any serious accidents recently. Nevertheless, the greatest difference is that Nolato receives statistics on risk observations more frequently, since they urge employees to report any deviation weekly, in their strive for continuous improvements. Obviously, the risks of having a serious accident at Nolato are lower.

6.2.3 Prioritized challenges

Based on the cross-case analysis, the most influential challenges on TePe's overall performance is presented in *Table 6.1*, together with possible TPS/Lean constructs to mitigate them. Each challenge has a reference to its research question in parenthesis.

Table 6.1. Prioritized challenges and possible constructs.

Prioritized challenges (see Chapter 5/6)	***Possible constructs (see Chapter 7)***	
Carelessness among personnel (1)	7.3.1 Genchi genbutsu	7.3 Managerial principles
"Us-versus-them" thinking (1)		
Visualization (1)	7.3.2 Visual management	
No zero defect policy (2)	7.3.3 Kaizen	
No structured way for continuous improvements (1, 2)		
Solving problems temporarily (1)	7.3.4 5 Whys	
Non-aligned KPIs (2)	7.3.5 Re-evaluation of strategies	
Flow efficiency (1)		

Chapter 7. Development of Constructs at TePe

Based on the prioritized root causes closing Chapter 4 and the prioritized challenges closing Chapter 6, this chapter assesses and develops constructs for TePe. A basic model of this chapter's structure is first presented, followed by the actual constructs. Each construct is, then, concluded through a brief paragraph assessing implementation aspects. The research questions pervade the entire chapter.

7.1 Structure

This chapter is built upon prioritized root causes and challenges that TePe faces, at least according to this paper. A basic model of this chapter's structure is presented in *Figure 7.1*, in which the prior research question (i.e. efficiency challenges) pervades the entire chapter, but is mainly influenced by the first three sub-chapters. This is due to flow efficiency being TePe's most alarming challenge/root cause. The other research questions (i.e. new production unit and safety challenges) is primarily influenced by the final three sub-chapters, based on the root causes identified in *Chapter 4*.

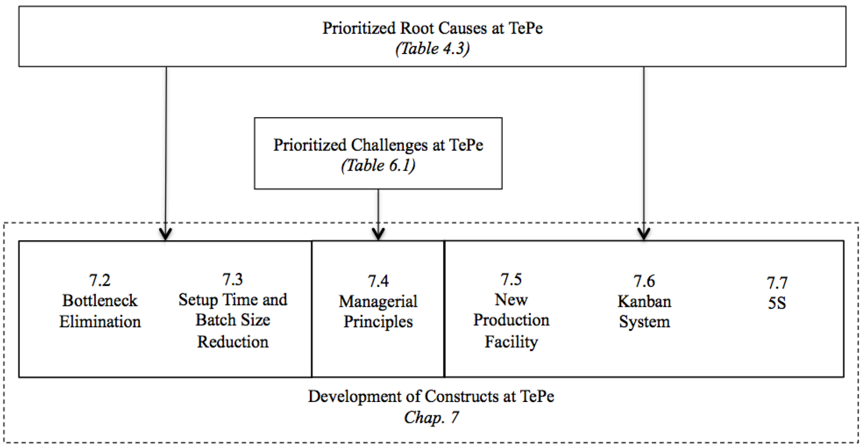

Figure 7.1. Structure of Chapter 7.

7.2 Bottleneck Elimination

There is always a bottleneck in any system; the operations at TePe are no different. Not only is it important for TePe to initially identify the bottleneck, but also to develop a structured process of increasing its capacity, especially due to TePe's objective of a yearly organic growth and expansion. This paper follows the five-step method in bottleneck elimination presented in *Chapter 2.17*.

7.2.1 Bottleneck identification

Uncertainties around which operation is the actual bottleneck in the system have arisen by employees at TePe. Especially in the production facility change, there have been concerns from operators about an elevator, which will connect the two floors, becoming a bottleneck. It can be stated right away that the elevator, which fits a maximum of four pallets, is not a bottleneck.[37] Therefore, the elevator is not part of the following bottleneck identification. Neither is the mixing operation part of this bottleneck identification since it has no machine-based capacity constraints.[38] Annual process capacities for both injection moulding and assembly/packaging are illustrated in *Table 7.1* below. The calculations are based on an altered version of *Equation 1* from *Chapter 2.17*, and described in *Appendix XIV*. Note that the annual demand last year was 19 900 000 pcs.

Table 7.1. Annual process capacities of each operation to identify the bottleneck in TePe's system.

Operation	***Process capacity [pcs/year]***
Injection moulding	22 023 062
Assembly/Packaging	26 624 000

Even though previous calculations required several assumptions (see *Appendix XIV*), such as average batch sizes, setup times and takt times for a wide variety of products, *Table 7.1* clearly indicates that injection moulding is the bottleneck. This is counter-intuitive since many toothbrushes are stored for several weeks in intermediate storage, waiting for assembly/packaging. The reason for that is rather assembly/packaging's need for several different colors before starting. Having that in mind, the bottleneck identification makes sense.

7.2.2 Increasing bottleneck capacity

It is essential to maximize the utilization of the bottleneck, in this case the machines in injection moulding, to eliminate congestions due to TePe's wide product portfolio including many colors, and by this action increase flow efficiency. It is, however, important to still keep injection moulding the bottleneck, since a bottleneck early on creates a better flow through the system. There are a few possible ways of increasing a bottleneck's capacity: one being to invest in new machinery, which TePe evaluates as I write this. Another is by reducing setup times, or also by balancing batch sizes.

[37] Based on a daily demand of six full pallets of semi-manufactured products and two full pallets of raw materials (see *Appendix XVIII* for Kanban calculations).
[38] Mixing is a highly flexible operation not using any machines. The available capacity can easily be increased by hiring or rearranging personnel. This is not the case for other operations, which need machine investments or changes in capacity requirements.

Since this paper emphasizes both of them as prioritized challenges for the company, following sections will examine such possibilities of reducing either setup times and/or batch sizes.

But first, an evaluation of how annual capacity changes by adjusting either setup time or batch size is needed to illustrate how a bottleneck's capacity can be affected at TePe in practice. Examples may illustrate the case, in which both batch sizes and setup times are changed periodically, as is illustrated in *Table 7.2* below.

Table 7.2. Annual process capacity in number of toothbrushes with different batch sizes and setup times (note that annual demand is 19 900 000 pcs and today's capacity is underlined).

Batch size [pcs] / ***Operation***	***300***	***900***	***1800***	***3600***	***7 200***	***14 400***	***Setup time [min]***
Injection moulding	8 403 537	14 515 200	17 740 800	19 958 400	21 288 960	<u>22 023 062</u>	***120***
Assembly/ Packaging	4 278 857	9 984 000	14 976 000	19 968 000	23 961 600	<u>26 624 000</u>	
Injection moulding	12 282 092	17 740 800	19 958 400	21 288 960	22 023 062	22 409 431	***60***
Assembly/ Packaging	7 488 000	14 976 000	19 968 000	23 961 600	26 624 000	28 190 118	

There are a number of takeaways from *Table 7.2*. First, there is a possibility to minimize batch sizes greatly without reducing setup times, all depending on the company's need for overcapacity. As long as TePe experiences high variability in demand, some overcapacity is although beneficial to keep. Second, setup time reductions naturally have a slight impact on capacity with already large batch sizes, but greater impact on smaller batch sizes. Note that a setup time reduction by half retains the same capacity even though batch sizes are reduced by half. This is illustrated by the graphs in *Figure 7.2*. The graph is pushed leftwards when setup times are reduced, enabling smaller batch sizes but, still, maintaining similar or even better capacity. The figure also shows theoretically possible batch sizes, for different setup times in parenthesis, with no overcapacity. The aim is to come as close to the intersection with "annual demand" as possible, without dangering delivery precision due to variability in demand.

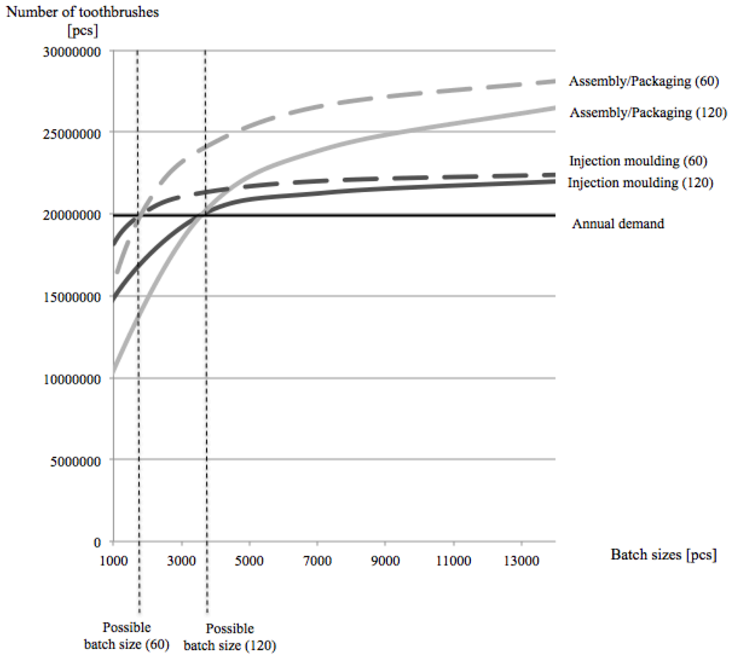

Figure 7.2. The effect of a setup time reduction on annual capacity at TePe.

In conclusion, setup times and batch sizes are interrelated; if the former is reduced, the other can be reduced. In turn, these actions mitigate many of the challenges TePe faces linked to efficiency, such as long lead times, much tied-up capital and low flow efficiency. The following sections investigate such a step-by-step evaluation.

7.3 Setup Time Reduction

TPS/Lean provides the SMED approach to investigate a setup time reduction, and, therefore, this paper applies the same methodology from *Chapter 2.8.5*. Note that I do not apply an in-depth SMED analysis onto TePe's machine park due to time restrictions, but a briefer analysis on an injection moulding machine based on estimations from several technicians to understand improvement opportunities.

7.3.1 SMED analysis

This SMED analysis is performed in different steps, basically by (1) dividing the changeover into smaller tasks, (2) estimating actual net time spent on each task, (3) separating between IED and OED, (4) converting IED to OED and (5) starting over from step three. Each turn becomes an implementation stage, based on different implementation costs for TePe.

The analysis concluded three implementation stages, namely (1) advance preparation, (2) standardization and (3) automation. The actual calculations and assumptions are appended, as well as explanations of each stage and also some advice before an implementation (see *Appendix XV*). The total setup time in injection moulding is estimated to be around 118 minutes, with worst-case scenarios at 1236 minutes. Note that both estimated setup time and, later, suggested reductions are approximate numbers only to understand improvement opportunities.

7.3.1.1 Advance preparation (Stage 1).

Many tasks can be performed in advance of a changeover. TePe technicians do apply this rule sporadically, but not as a standard. Instead, a technician may stop the machine, and *then* retrieve both relevant tools and plastic granules, and *then* move the overhead crane. In fact, there may also be some searching and phone calls before finding the right tools. This stage, therefore, includes a 5S implementation and a short introduction of Lean to technicians. For the 5S implementation, see *Chapter 7.6*. More detailed information about this stage is appended (see *Appendix XV*).

7.3.1.2 Implementation.

The implementation of this stage is the simplest and least time-consuming, but also the stage with least impact on time reductions. However, setup times can be reduced by around 20 per cent to 94 minutes in the short-term. The education is estimated to take a few hours, and includes all technicians.

7.3.1.3 Standardization (Stage 2).

There is no actual standardized work procedure for changeovers at TePe. Since the process for the technician seems simple and straightforward, no setup sheet has been created. If a process is simple this is even more of an incentive in creating a setup sheet, since it will streamline the optimal work processes. The setup sheet needs regular updates in consulation with the technicians, enforcing the company to continuously improve.

Many opportunities on improvements have been found related to standardization. Technicians performing specific tasks in parallel are, for example, not prioritized by the company. Instead, this happens occasionally. Neither is there a standard procedure on how to change color granules from brighter spectrums to darker spectrums. This challenge can also be mitigated by investing in purge compounds to clean machines from colors or materials in a changeover. More information about these improvement opportunities is presented in *Appendix XV*.

7.3.1.4 Implementation.

An implementation of this stage can reduce the setup times by around 56 per cent to 52 minutes in the long run. This stage needs an initial investment cost of 120 000 SEK, primarily for wages over a two- to three-week period. For more information about these implementation costs, see *Appendix XV*.

7.3.1.5 Automation (Stage 3).

A full-automation of the changeover process can reduce setup times significantly. This requires an investment in a quick mould changeover system, such as a vertical or horizontal mould loading system, for many of TePe's injection moulding machines.

7.3.1.6 Implementation.

An implementation of this stage can reduce the setup times by around 92 per cent to 10 minutes. The investment costs of such an implementation is, however, difficult to assess. It is vaguely defined as a "high capital investment", and needs to be evaluated by upper management in parallel with a re-evaluation of the company's strategies. What can be said is that it probably needs a re-arrangement of machines with another expansion of the production facility to fit an automation of changeovers, and, therefore, is seen as an even costlier process. An implementation should, however, not be completely ignored since it would lead to a possibility of significantly decreasing batch sizes, leading to several competitive advantages for the company. It would also lead to a safer environment, less defects and better efficiency. In this paper, withal, an implementation is not further investigated due to the magnitude of such an investment.

7.3.2 Batch size reduction

There is a constant conflict between setup costs and holding costs in a manufacturing firm. From this conflict stems the economic order quantity (EOQ) formula (Schonberger, 1983), which has been the traditional way of calculating batch sizes. However, the formula is built on assumptions not fulfilled at TePe, such as a steady demand and, more importantly, pre-determined setup costs. Instead, this paper tries to reduce batch sizes as much as possible to strive for a theoretically optimal one-piece flow. With a 56 per cent reduction of setup times, which is possible by implementing SMED at TePe, there is an opportunity of a 34 per cent batch size reduction, based on the EOQ formula (Olhager, 2013). This maintains the same capacity. Since TePe have some overcapacity, a further reduction to an average of 7200 pieces, i.e. half of current batch sizes, is possible without even affecting the capacity significantly.[39] A 50 per cent reduction in batch sizes leads to an equally large reduction in tied-up capital. For TePe, this means a release of 3.7 MSEK in tied-up capital, as well as 0.74 MSEK saved yearly in inventory holding costs.[40] Furthermore, such a batch size

[39] The new capacity for injection moulding is 21 788 149 pcs, based on interpolation.

[40] TePe does not have any standard policy on calculating inventory holding costs. Research by Azzi, Battini, Faccio, Persona and Sgarbossa (2014) suggests that *"inventory holding cost parameters range between a minimum of 21.9 and a maximum of 32.9 percent of the inventory value on hand"* (p. 125), based on five case study companies. Inventory holding costs, in this paper, are conservatively assumed to be 20 per cent of the product toothbrushes' total inventory value.

reduction leads to a direct lead time reduction. Waiting times is, basically, reduced by half. For TePe, this means reduced lead times in intermediate storage from in average six to three weeks, mitigating the congestions between injection moulding and assembly/packaging. Moreover, it means reduced lead times in finished goods warehouse from in average eight to four weeks. Most likely, this leads to higher asset turnover, increasing ROI, which is another challenge TePe faces.

In the long run, less inventory also leads to indirect labor cost reduction (Schonberger, 1983) in terms of less inventory accounting, better visibility of materials and smaller warehouses. Smaller batch sizes create a chain reaction of other benefits as well (Schonberger, 1983). Many of them are difficult to quantify, but very likely are the results less defects and better quality of products (Schonberger, 1983). An example can illustrate the case. A technician at TePe may produce a batch for several days full of defects. With reduced batch sizes, the feedback, both constructive and positive, reaches upstream operations quicker and mistakes can be adjusted faster. This, in turn, leads to an increase in the technician's awareness of challenges and their root causes, which further leads to improvements such as (1) defect prevention, and ideas on (2) better flow efficiency and (3) even shorter setup times (Schonberger, 1983). Therefore, it is also important to give staff the opportunity to easily share their ideas to allow for, and encourage, continuous improvements.

Finally, less defects and better quality obviously also leads to less scrap as well as less time and costs for rework (Schonberger, 1983). Another indirect benefit of small batch sizes is the elimination of carelessness among operators (Schonberger, 1983) in a mass-producing company, such as a few hundred products piling up on the floor beneath an injection moulding machine at TePe.

7.3.3 Implementation

Batch size reductions are, like the entire concept of Lean, an ever-changing process, aiming for a one-piece flow. Therefore, I consider the idea of batch size reduction a long-term implementation, even though this paper's recommendation for TePe is seen as a short-term implementation based on a setup time reduction. However, the intermediate storage will be less space utilized, due to higher stock turnovers, after batch size reductions, whereupon pallet positions need to be trimmed occasionally. The implementation time is, therefore, difficult to predict, but the implementation costs are essentially nil. At least initially, since batches still can be transported on the same pallets.

7.4 Managerial Principles

TePe does have some improvement possibilities related to managerial principles, discussed in the gap analysis in *Chapter 6*. Building a culture to strive for perfection and constantly improve is necessary for the company, especially in regards to efficiency challenges. Putting effort into the managerial principles also mitigate the carelessness among personnel as well as the *”us-versus-them thinking”* partly established on the shop floor.

The importance of managerial principles can be seen in a future TPS/Lean implementation process at TePe, illustrated in *Figure 7.3*. The process is structured similarly to the Lean implementation process Nolato experienced and is also based on this paper’s findings about TePe. What influenced Nolato’s change greatly was (i) the management support, including their knowledge, participation and professionalism. TePe has some potential, based on the cross-case analysis, to improve in such areas, implementing TPS/Lean principles such as (1) genchi genbutsu, (2) visual management (3) kaizen and (4) 5 Whys. On top of that, (ii) a continuous re-evaluation of strategies was important for Nolato, and is important for TePe to align objectives with actual performance and practical work.

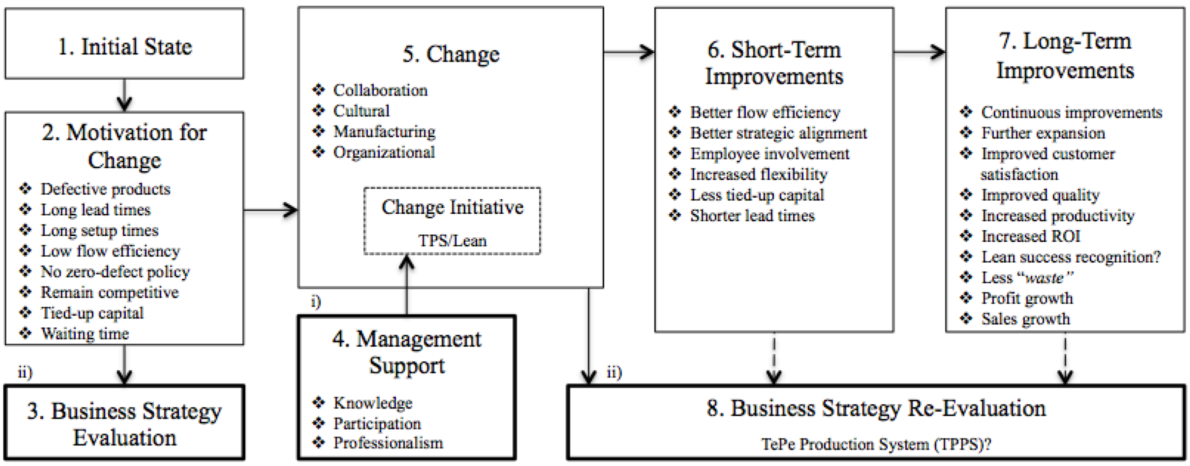

Figure 7.3. A possible TPS/Lean implementation process at TePe.

7.4.1 Genchi genbutsu

Building a new culture, such as a TPS/Lean culture, always starts with upper management, who needs to be commited to goals and strategies of the company (Liker, 2004). Management, then, needs to constantly communicate with employees on the shop floor, bridging any discrepancies. By making room for genchi genbutsu in their schedule, TePe management cannot only mitigate the *”us-versus-them mentality”* but also better understand root causes while spending time around the actual production of toothbrushes. Applying genchi genbutsu, or simply gemba walks, is, therefore, strongly recommended not only for the immediate supervisor but for senior management as well. This demonstrates commitment from management and shows operators the importance of their work, which, in turn, creates trust and motivation. The potential solution of any problem is also better received by the shop floor if operators have been heard, and operators are more likely to report problems in the future.

7.4.2 Visual management

Closely related to management devoting time to the shop floor is visual management. TePe does use process control boards in their production facility to show important data, but the information is only partly aligned with their KPIs. Visualizing all information enhances transparency and gives operators direct feedback on their performance. This paper recommends TePe to implement daily, or at least every other day, stand-up pulse meetings for each department, in the same spirit as Nolato has implemented (see *Chapter 5.2.3.12*). The meetings should be no more than 15 minutes, bringing up the most important information about the status of the production related to TePe's objectives as well as (potential) issues or improvement possibilities. The pulse boards should be easy to follow, advisably relating an issue to a TePe objective when the issue arises. Issues are always highlighted in a specific color based on the objectives. It is vital that the pulse board has a spot for issues and improvement possibilities specifically, in which anybody can fill in issues arising during the day. Pulse meetings can, generally, be used at all levels of a company, replacing many of the regular meetings. TePe would benefit from such actions since pulse meetings are more efficient than regular meetings, saving more time for value-added activities. There are many examples of pulse boards on the Internet, from which TePe can be further guided in a pulse meeting implementation. Other recommendations related to visual management are a 5S implementation (see *Chapter 7.6*) and a kanban implementation (see *Chapter 7.5*).

7.4.3 Kaizen

TePe does not have a structured system for continuous improvements today. To be able to foster a culture in which continuous improvements are seen as a vital part, TePe needs to give the employees the right tools for that, such as the pulse boards/meetings or similar. But more importantly, such a culture needs to be embedded at every level, starting from upper management down on the shop floor. If management is not convinced about the benefits of kaizen, the shop floor will not be either. To not meet resistance from operators in building a culture with continuous improvements, the operators need to be part of the change. Therefore, daily pulse meetings are vital for TePe rather than having weekly meetings. It is also important to implement managerial principles sequentially, over a longer period of time, for employees to get accustomed to TPS/Lean. That being said, employees at every level should be encouraged to find improvement opportunities. In the long run, this increases efficiency, productivity and employee engagement, bridging employees from different levels of the company.

The aim is to create a sense of responsibility in every employee, making them interested in their own work (Schonberger, 1983). This can be created by implementing what Toyota calls *small group improvement activities (SGIA)* (Schonberger, 1983). The department is, for example, divided into smaller groups with team leaders who meet regularly. This also gives room for employees to take on leadership roles. Research even suggests that interest among personnel arises not only by creating SGIAs, but to actually implementing Lean principles (see Schonberger, 1983). In fact, reducing inventory increases employee's interest in finding improvements (Schonberger, 1983).

An investigation of external- and internal-driven motivational methods (see *Chapter 2.7* for theory) is also suitable for TePe to increase employee's interest, since TePe constantly strives for organic growth and expansion. TePe does work with goal setting motivation today, such as visualizing daily expected production versus daily produced toothbrushes. Management can, however, be more transparent in visualizing personal goal setting for operators to give them incentives for kaizen. Another external-driven method for TePe can be to establish an incentive system with monthly rewards for employees if reaching some accumulated number of produced toothbrushes.

7.4.4 5 Whys

Issues automatically arise at shorter time intervals when genchi genbutsu is applied to a great extent. More importantly is, then, the methods of 5 Whys in finding root causes, not only for management at TePe but for operators. Instead of only solving problems temporarily to restart production, operators need to be educated in solving problems permanently.

7.4.5 Re-evaluation of strategies

The re-evaluation of strategies is, as other managerial principles, a continuous on-going business, as illustrated in *Figure 7.3* above. Most essential is that the strategies pervade the entire company, from upper management to the factory floor. Therefore, it is important for TePe to, initially, re-evaluate their strategies. The OEE is, for example, one of the most important performance metrics used in a manufacturing business to evaluate productivity and quality issues (Binti Aminuddin, Garza-Reyes, Kumar, Antony & Rocha-Lona, 2016). A correlation between companies working with improvement efforts such as Lean, and their use of OEE as a KPI has also been found in research (see e.g. Binti Aminuddin et al., 2016). The OEE metric, which is already applied at TePe, is, therefore, a good start. The metric, however, does only account for resource efficiency, which has been the strategy TePe uses, especially with automation. Operations in-between machines are hidden using only the OEE, and, thus, the metric lacks in aspects related to flow efficiency. Since this paper has found the flow efficiency being of crucial importance in enhancing TePe's overall performance, the KPIs are recommended to be expanded. Examples of relevant KPIs for TePe are, therefore, the activity ratio[41] and ROI[42] (see Brewer & Speh, 2000). Especially is the activity ratio a hands-on KPI, measuring the value-added time spent in production against the lead time. Both KPIs serve as complement to current metrics. However, I recommed TePe to also re-evaluate their current KPIs since many companies in general lack in linking their strategic goals with their supply chain management practices (Brewer & Speh, 2000). For this process of strategically aligning objectives with performance metrics, the *Balanced scorecard* presented by either Brewer and Speh (2000) or Kaplan and Norton (2007) can be used. An Internet search can guide the reader to similar balanced scorecards. Companies use the scorecard to update, communicate and clarify their strategy as well as to focus on desired improvements in performance (Kaplan & Norton, 2007). Another, probably even more relevant, performance measurement system is the *Supply chain operations reference (SCOR) model*, developed by experts and practitioners from the Supply Chain Council (Wang, Chan & Pauleen, 2009). The model is specifically designed for supply chain planning, including both supply chain management practices and business process reengineering (Wang et al., 2009).[43] This paper, however, does not evaluate TePe's strategies further due to both time restrictions and the actual evaluation being more suitable for TePe upper management to proceed.

7.4.6 Implementation

This paper refrains from quantifying the benefits of applying managerial principles, which although certainly enhances the overall well-being of the company in the long run. Such quantification would be highly hypothetical, since every company reacts differently on a cultural change. For the reader who is not yet convinced of the effects from managerial principles, Nolato can serve as example. They, today, have an asset turnover of 1.57, and has doubled their ROI over a twelve-year period.

Note that there is not the actually recommended TPS/Lean methods that are most important, but rather to achieve employee engagement (see Schonberger, 1983). This implementation requires time invested continually from each employee over many years, and, therefore, neither is this implementation quantified in terms of time or costs.

7.5 New Production Facility

The new production facility initiates a few challenges, but, most importantly, keeping high materials availability on the second floor. The layout has already been planned by TePe management, and is illustrated in *Figure 7.4*. Even though Lean suggests a cellular layout with continuous flow, there were, according to management, many factors influencing the layout

[41] The activity ratio is the ratio between processing time and lead time used in value stream mapping.
[42] ROI measures the ratio between profit margin and asset turnover.
[43] Both the Balanced scorecard and the SCOR model application at TePe requires further research since it goes beyond the scope of this paper.

decisions, such as (1) a two-floor production, (2) weight restrictions on machines and (3) mixing needed between injection moulding and assembly/packaging. However, this paper suggests adding (i) a relocation of mixing and (ii) a supermarket on the second floor. As is illustrated in *Figure 7.4*, both areas are located to enabling a U-flow of products. Note that not all areas are utilized in the new production facility due to possibilities of further expansion.

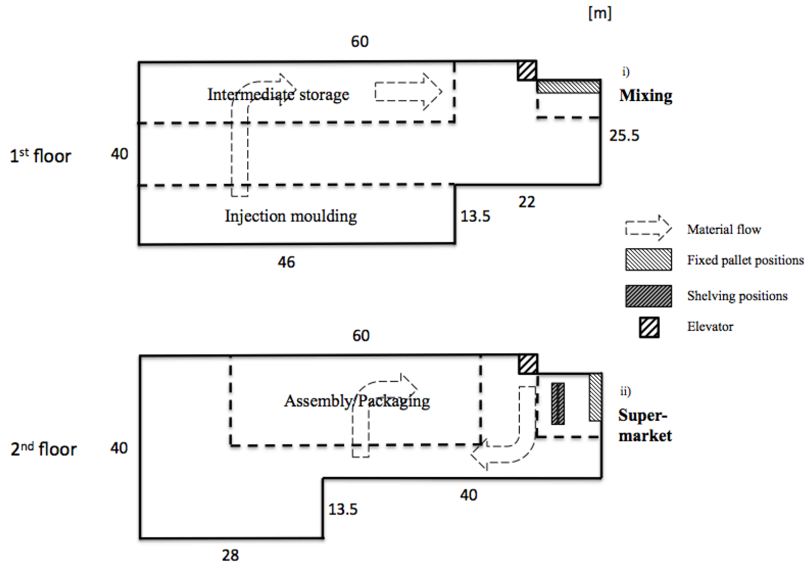

Figure 7.4. A possible layout for the new production facility for toothbrushes.

7.5.1 Relocation of mixing

A few safety hazards have been found while conducting this paper, the most critical being operators at times working alongside moving forklifts, without any area restrictions. By relocating mixing, those safety hazards are mitigated significantly. The suggestion is to move the operation closer to the elevator, facilitating a better flow of products. After semi-manufactured products have been mixed, they are stored on pallet positions within this marked area waiting for transportation to the second floor. If production planners or production supervisors plan production properly, mixing is performed a day before assembly starts, which means that tomorrow's production is transported by warehouse operators to second floor during the evening shift. The pallets are put away in a racking system within the supermarket.

7.5.2 Supermarket

A supermarket located on the second floor can secure that raw materials and semi-manufactured goods are always available for production. Challenges such as materials accessibility and storage in the new production facility are both mitigated, or even eliminated, by creating a supermarket. A supermarket also gathers all articles in a single area, which increases visibility, rather than raw materials being spread around the facility. Since there is no paternoster lift available[44], as well as no structured technique of planning production on a daily basis, TePe management agreed on storing every unique article for assembly/packaging (i.e. 119 articles of raw material) in the supermarket. The supermarket, therefore, works like a smaller intermediate storage, controlled by a kanban system (see *Chapter 7.5*). The difference is that it is replenished from RMW rather than the actual intermediate storage. The layout of the supermarket should be space utilized, easy to access from both the elevator and production, and ergonomic for operators to work within. An example of a layout is illustrated in *Figure 7.5*.

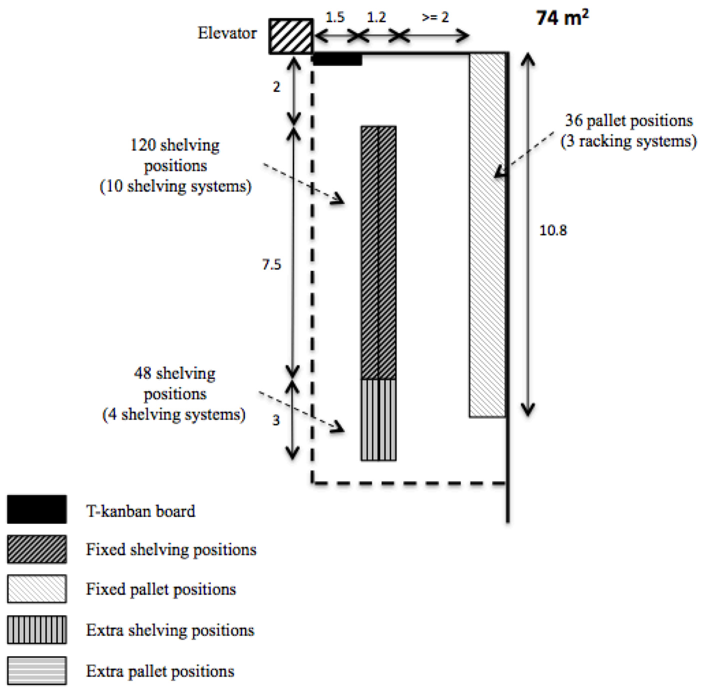

Figure 7.5. Proposed layout of the supermarket.[45]

As can be seen in *Figure 7.5*, the supermarket consists of both pallet positions and shelving positions. This is due to practical reasons such as bulky articles being stored on pallets while smaller articles being stored on shelves. In total, the supermarket consists of 36 pallet positions in a racking system and 168 shelving positions. Due to the company's overall aim on expanding and introducing new articles to the market, the supermarket has been designed with more positions than necessary. TePe management requested this. It is, however, important to revise the positions regularly, aiming for a minimization. In the short-term, the extra positions can be used in periods when demand peaks. For more details on the layout, see *Appendix XVI*.

[44] This paper assumes that no investment in a new paternoster lift is possible for the new production facility. The assumption is based on building permits.
[45] Note that the layout is not drawn to scale.

Not only does a supermarket increase both accessibility and visibility of materials, but also space utilization. In line with TePe's objective to continuously expand their production, a supermarket contributes to a 54 per cent reduction in space used.[46] By establishing a supermarket, operators are also separated from moving forklifts, which not only decreases safety hazards significantly, but, in fact, eliminates them altogether. Not investing in a supermarket at all, however, would lead to great losses due to long distances between RMW and assembly/packaging, as well as they being located on different floors. Only lost production due to extra time spent on replenishment will be worth a few million SEK yearly. The case can be illustrated by an example. An assembly/packaging operator needs to replenish an article, thus, stops the machine and walks to intermediate storage on the first floor. He may as well be forced to wait for the elevator for a few minutes. Assume that the replenishment time is ten minutes, instead of one minute with a supermarket. If this scenario happens to every operator once a shift, it leads to lost production of 561 600 toothbrushes yearly.[47] Based on an estimated average profit margin of three SEK per product, 1 684 800 SEK is lost yearly.

7.5.3 Implementation

Both the relocation of mixing and the supermarket need area restrictions in terms of painted lines. The implementation of the supermarket is, however, more time consuming; this paper expects a two days to one week implementation for two employees for a 25 000 SEK investment. For more details about implementation costs of the supermarket, see *Appendix XVI*.

7.6 Kanban System

Several challenges related to either efficiency or safety can be mitigated by implementing a kanban system for the supermarket at TePe. For example, the kanban system initiates a structured replenishment procedure to assembly/packaging. It also minimizes tied-up capital, since it keeps an upper limit of WIP, enhancing flow efficiency through the company. This paper suggests a single, fixed quantity, kanban system with T-kanbans for raw materials between RMW and assembly/packaging. In addition with the pulse boards, the kanban board increases visibility, in this case visualizing actual demand of raw materials for employees all over the facility. Visibility, in turn, increases employees' focus on continuous improvements and self-discipline. A physical kanban system is, therefore, preferred over an electronic kanban system, at least as a starting point.

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[46] Based on 44 pallet positions holding 1.2*0.8 m^2 each in current layout and 36 pallet positions holding (1.2*0.8)/(3 floors) m^2 in the new layout, while 63 shelving positions in current paternoster lift hold (0.6*0.5)/(13 floors) m^2 and 113 shelving positions in new shelving system hold (0.6*0.5)/(4 floors) m^2.

[47] Based on ten machines manufacturing an average of twelve pcs/min over two shifts, nine minute replenishment time and 260 workdays.

TePe should, however, evaluate extending the kanban system into a dual kanban system with P-kanbans for toothbrush production in the future, bringing many benefits. This is not evaluated in this paper due to several reasons, such as TePe's long setup times and large batch sizes, as well as their high variability in demand, which are all subjects for improvement before such an implementation. More information on extending the kanban system is appended (see *Appendix XVII*).

As is illustrated above, TePe gains many benefits by implementing a kanban system, even though the monetary impact of several is quite intricate to anticipate. A result should, however, for example, be a reduction of tied-up raw materials in intermediate storage by around 50 per cent.[48]

7.6.1 Replenishment procedure

The kanban system works like a link of information between the RMW and assembly/packaging. A schematic outline of how the single kanban system procedure will work at TePe is illustrated in *Figure 7.6*.

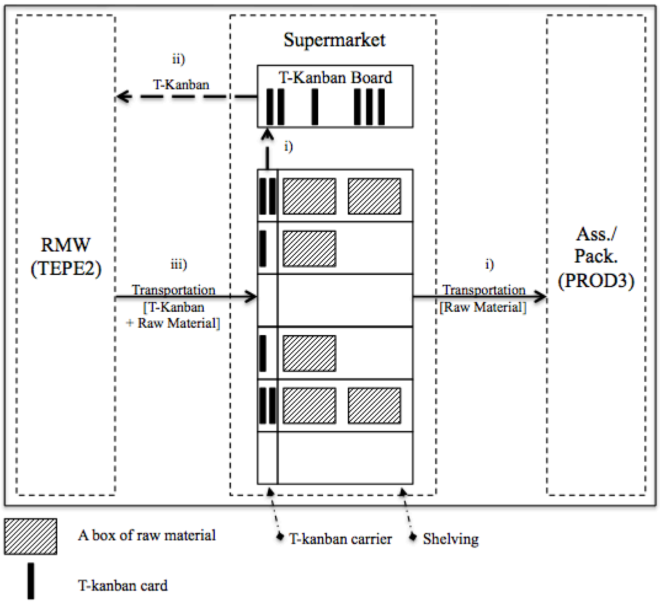

Figure 7.6. A schematic outline of the new kanban procedure at TePe.

It is essential to understand the basis of this new replenishment procedure at TePe, and, therefore, an explanatory case is attached below.

i) Every article being part of the kanban system has a T-kanban card, which is stored in a card carrier (akin to a brochyre holder) in front of, or next to, each shelving position *when* the raw material is available for production. When an assembly/packaging operator needs raw material, they

48 A pallet in intermediate storage is estimated to contain in average eight boxes of raw materials, while a position in the new shelving system is estimated to contain in average two boxes. The calculation is based on data from *Appendix XVIII*.

first transport the associated T-kanban card to the kanban board, which is a signal for demand in the supermarket, and, then, transport the articles to the assembly/packaging area.

The kanban board consists of card holders, such as hooks, racks or magnets, for the kanban cards to be stored, one for each unique article of raw materials. Above each card holder is the article name or number. When the right amount[49] of cards is located on a hook, this is a signal for replenishment. The kanban board visually shows the need of raw materials for anybody, either operators or management.

ii) The warehouse operators checks the kanban board twice a shift. If there are enough cards on the card holder to initiate a replenishment of that article, she removes (!) the cards from the board and brings them back to RMW (TEPE2). Note that she replenishes all unique articles ready for replenishment simultaneously. She, then, registers the replenishment in TePe's internal system, Jeeves, exactly as is done today.

iii) The actual replenishment is initiated. The warehouse operator replenishes the raw materials into the shelving system, and put the kanban cards in the T-kanban carrier. Again, since the distance between RMW and the supermarket is quite long, the warehouse operators should strive for transporting as many different articles as possible in a single turn, if possible.

7.6.2 Kanban cards

Every article stored on shelves in the supermarket is included in the kanban system, at least initially. This is due to the importance of having no stock-outs. The system contains 219 kanban cards. Detailed information about articles' number of kanban cards, safety stock levels etc. can be found in *Appendix XVIII*.

7.6.3 Kanban assumptions

It cannot be emphasized enough that a too detailed analysis of the amount of kanban cards is in fact inappropriate, since the real world always differ from such an analysis (Yamashina, 1982). Remark that the calculations of this paper, therefore, is only a recommendation, and definitely no final answer. Such a calculation also includes many assumptions, and, therefore, I shortly argue for assumptions regarding the most important variables: (1) the safety coefficient, (2) demand, (3) lead times and (4) container size.

The safety coefficient was, first, set to $\alpha = 0.5$, which means that half a day's extra demand is always stored within the supermarket. Guidance from TePe later led to an even higher safety factor to eliminate risks of stock-out, yet implementing too many kanban cards is no problem as long as there is a gradual decrease in cards (Shingo, 1984).

[49] Each kanban card has this information.

A forecasted average demand of each article is based on either previous year's use of raw materials in production or the actual demand for specific toothbrushes. However, since demand is not always easy to predict, many articles has been given extra cards, and, therefore, the importance of cutting cards is of even higher priority.

The replenishment lead time is quite an uncertain variable. For T-kanbans, however, this variable can certainly be simplified by assuming that raw materials are always available in the RMW. Then, the internal replenishment lead times can be assumed to be four hours, since I expect warehouse operators to check the kanban board twice a shift. That being said, the replenishment itself should take between 10 to 30 minutes depending on the number of unique articles, which means that there is even less risk of stock-outs as long as operators communicate. If an operator finds a shelf empty, it is important that she communicate with warehouse operators for an immediate replenishment.

Container sizes are simply based on practical reasons, such as a purchased full box of an article or a roll of another article. By using such container sizes, extra work is eliminated and investment costs are minimized.

7.6.4 Kanban planner

Since the kanban system is never constant but needs continuous updates, kanban buffers may decrease over time. It is actually paramount for them to decrease to strive for a continuous flow with JIT. Since adjustments and updates of WIP are essential for the kanban system to be beneficial, a new role as kanban planner at TePe is suggested. The position is advisably divided onto two employees, one from RMW and one from assembly/packaging, since the departments/operations are linked with the kanban system. By communicating over departments, many hidden challenges will arise to the surface. More practical information and advice about the kanban implementation at TePe is found in *Appendix XIX*.

7.6.5 Implementation

Despite this paper's guidance, preparations and some projects are a necessity before implementing a kanban system; some new equipment needs to be purchased, new responsibilities must be established and general preparations are needed. Simple guidance in needed projects is appended (see *Appendix XIX*). A kanban implementation is roughly estimated to cost 60 000-80 000 SEK, including the purchase of shelving systems, over a two-week implementation period for around five employees. A more thorough implementation cost estimation can also be found in *Appendix XIX*.

7.7 5S

As TePe also meets safety related challenges within the production facility, a 5S implementation is beneficial for them. Every equipment, in both injection moulding and assembly/packaging, will have its own spot, mitigating safety hazards due to less movement of operators searching for tools. TePe, in fact, experiences non-value added time spent on such activities, as well as, at times, a non-structured work environment. Both are mitigated by a 5S implementation. Employees also need to keep equipment and their work environment clean, no matter the operation.

As a few other constructions of this paper, the advantageous of implementing 5S is difficult to quantify in monetary terms. However, imagine three operators or technicians spending ten minutes a day searching for a tool. Over a year, 130 hours have been wasted on non-value added activities. If this also prevents the production from manufacturing accordingly, there is a loss of around 94 000 toothbruhes. Depending on how far up in the value stream the production is stopped, the added product value is obviously different, but the total value on lost production is estimated to be around 0.28 MSEK yearly.[50]

7.7.1 Implementation

The project of implementing 5S can be divided into two phases: (1) the actual implementation of 5S and (2) sustaining 5S. Although the actual implementation of 5S may be simple, it is harder to sustain. The importance of implementing the managerial principles (see *Chapter 6.3*) can, therefore, not be emphasized enough.

The entire 5S project is seen as a *"low-cost investment"* of around 20 000 SEK with an actual implementation time of one week, including the workforce of an entire department (5-20 employees). Since education and follow-ups can be assigned the weekly meetings at TePe, and the culture of continuous improvements should be embedded within the company via managerial principles, sustaining 5S is seen as a zero-cost investment. More detailed information about implementation times and costs as well as responsibilities and some advice is found in *Appendix XX*.

[50] Assuming 260 workdays a year, a production takt time of five seconds and an average product value of three SEK.

Chapter 8. Recommendation of Constructs at TePe

This chapter recommends the constructs guiding improvements for TePe. The constructs are, initially, evaluated economically to understand the extent of an implemtation, followed by a sensitivity analysis of each construct. Based on execution ease and anticipated benefit, this chapter prioritizes the constructs. Some advice for TePe in a TPS/Lean implementation concludes the chapter.

8.1 Evaluation of Constructs

This paper uses capital budgeting to create measurability between this chapter's constructs. The payback period method is used for TePe to understand implementation risks with each recommendation, since the method determines the risk period before the initial investment is paid back. *Table 8.1* summarizes the results from previous chapter, showing the payback period of each construct in the far right column.

Table 8.1. Economic summary of this paper's constructs.

Construct [51]	*Employees*	*Implementation time*	*Implementation cost*	*Positive yearly impact*	*Payback period*
Setup time and batch size reduction	6	2 – 3 weeks	0.12 MSEK	0.74 MSEK[52]	2 months
Managerial principles	All	~ 10 years	–	Asset turnover increase[53]	–
Supermarket/Kanban	~ 5	2 weeks	80 000 – 100 000 SEK	1.68 MSEK	3 weeks
5S	5 – 20	1 week	20 000 SEK	0.28 MSEK	1 month

As can be seen in *Table 8.1*, the majority of recommendations have relatively short payback periods, based on (1) implementation cost and (2) positive yearly impact. This paper refrains from evaluating costs of implementing managerial principles, since this would be a highly hypothetical estimation over a long timespan. The estimation would, basically, be too uncertain considering the time and costs necessary to change each TePe employee's mindset. The construct is part of the

[51] The constructs were validated by key employees at TePe in a workshop (see *Appendix II*). Out of the participants who filled out an evaluation sheet of the recommendations, all were certain about considering the constructs, giving them an average value of 2.5 (in a scale 1-3).

[52] There is also a release of tied-up capital to a value of 3.7 MSEK, which is not included in the payback period. The release will, however, lead to an even shorter payback period, a higher asset turnover and an increase in ROI.

[53] If TePe follows last decades asset turnover curve of Nolato, their asset turnover will increase by 24 per cent to 0.79, giving them a new ROI of 0.24.

economic summary, however, to emphasize its potential. Note, also, that relocation of mixing is not part of the economic summary, since it simply does not make any sense converting employee's safety into monetary terms; safety should always be number one priority. Not only are there factors of uncertainty in abovementioned constructs, but in many variables of the other constructs; thus, a sensitivity analysis is performed.

8.2 Sensitivity Analysis

There are, first, some general remarks necessary about the calculations of variables such as (1) implementation cost and (2) positive yearly impact. Implementation costs are, in this paper, the initial cost of implementing a construct. However, some constructs, e.g. setup time reduction, may need continuous improvements during a longer period of time, implying a higher cost. But since positive yearly impact is based solely on the easiest parameter to be measured quantitatively, the variable is highly undervalued. A construct, in fact, often brings a chain of other benefits, both indirect and direct, more difficult to account for.

8.2.1 Setup time and batch size reduction

This paper assesses a significant setup time reduction to be possible for TePe. However, instead assume only a 30 per cent reduction with now estimated efforts. This would still provide for a 17 per cent reduction in batch sizes, giving the company a positive yearly impact of 0.25 MSEK only in inventory holding costs.[54] The payback period is, then, six months. The benefits from the chain reaction can, however, not be emphasized enough. Only with a 30 per cent setup time reduction, lead times in intermediate storage and FGW would be two and a half weeks shorter in total, increasing flow efficiency, flexibility, customer service and so forth, and still reduce tied-up capital affecting ROI positively.

8.2.2 Supermarket/Kanban

This paper anticipates lost production to a value of 1.68 MSEK yearly if these constructs are not implemented. There are a few independent variables affecting this assumption. For example, assume instead an extra replenishment time, without the constructs that is, to be five minutes. This gives lost production of 0.94 MSEK. Further assume that assembly/packaging operators find a way of storing some raw materials, which they have picked up before their shift started, close to each machine. Such an assumption may decrease number of replenishments by half, decreasing lost production to 0.47 MSEK. Despite both of these alterations, the payback period is still only eleven weeks.

[54] Based on the EOQ formula, an inventory value of 7.4 million SEK and a 20 per cent inventory holding cost.

8.2.3 5S

This paper anticipates lost production to a value of 0.28 MSEK yearly if this construct is not implemented. Assume that there is only one employee, instead of three, searching for a tool each day. Lost production is, then, estimated to be 94 000 SEK yearly, leading to an eleven-week payback period. It should be added that this construct, like many others, contributes to a TPS/Lean culture, leading to indirect benefits in efficiency as well as safety, serving as a start in implementing managerial principles at the company.

8.3 Recommendation of Constructs

Based on both the evaluation and the sensitivity analysis, the constructs are prioritized using a PACE chart, illustrated in *Figure 8.1*. The constructs are, basically, assessed on (i) execution ease and (ii) anticipated benefit for TePe. This paper also considers each construct to be implemented either in the short-term or in the long-term. Note, however, that (1) setup time and batch size reduction, (5) kanban system and (6) 5S are all constructs requiring long term efforts as well, even though the actual implementation is seen as a short-term recommendation.

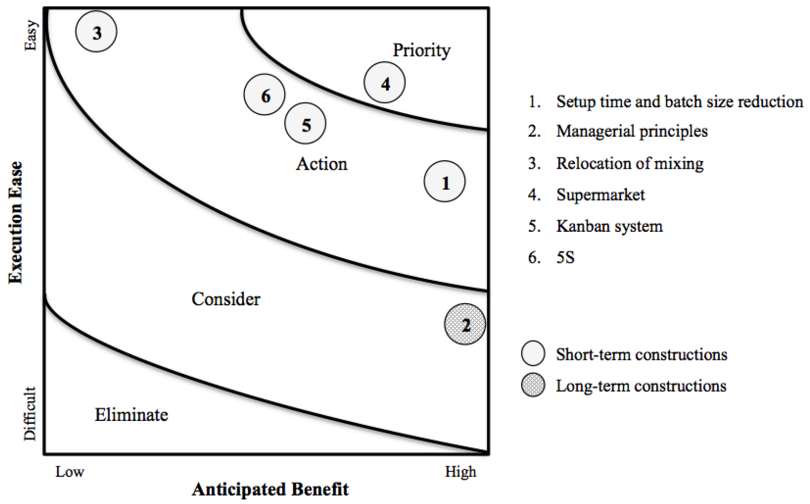

Figure 8.1. Evaluation of recommendations for TePe.

8.3.1 Priority

The supermarket is the construct with highest priority for TePe. This is not only due to factors of the PACE chart, but also due to the construct being a necessity in the new production facility. TePe is recommended to prioritize an implementation of following construct: the supermarket.

8.3.2 Action

There are two constructs falling into each extreme of the ”take action” area. The setup time and batch size reduction is estimated to have a strong impact on TePe’s efficiency challenges, yet it requires some effort from the company. The relocation of mixing, on the other hand, is an easy-to-implement construct, yet not significantly impacting overall performance of the company. Both are, however, in the ”take action” area. The kanban system and the 5S implementation are both close to be prioritized, since they are both quite easy to implement mitigating many of the challenges TePe faces. In summation, TePe is recommended to take action to implement following constructs: setup time and batch size reduction, relocation of mixing, kanban system and 5S.

8.3.3 Consider

TePe is anticipated to benefit the most from implementing managerial principles. This paper suggests five methods (see *Chapter 7.3*) to implement in the long-run, influencing the culture of the company into TPS/Lean. Bringing every employee on board on such a project is hard, but the outcome can have a real impact on the overall performance of the company. Therefore, TePe is strongly recommended to consider an implementation of following construct: managerial principles.

8.4 Risk Assessment

There are always a few risks in any project; the same applies to the constructs of this Master’s thesis. Some of them are summarized below for TePe to better prepare for implementing this paper’s recommended constructs.

8.4.1 Resistance to change

Change is part of every improvement effort; TPS/Lean is no exception. Change often brings resistance to some extent, since resistance is a natural part of human behaviour. I, therefore, suggest that each employee affected by the construct in question is involved in the change. Some constructs of this paper, such as the kanban implementation, is divided into projects to facilitate such an employee engagement (see *Appendix XIX*). The empathetic aspect from management to always explain decisions for operators, preferably individually to avoid unnecessary conflicts, is also vital. Addressing the emotional responses, if there are any, at their root is a pressing factor to mitigate resistance. This is especially important while implementing the SMED analysis, since technicians may have been working in the machine park for decades already. In summation, employee participation is important, and no projects should be rushed.

8.4.2 Sustaining constructs

There is a risk of employees starting to take instructions lightly after a while. Operators/technicians may start to neglect putting back a tool in its place, or an operator may not be as accurate in moving kanban cards. Similarly, employees may, for example, stop cleaning their workplace everyday. It is, therefore, vital for management to be supporters of the constructs from start, as well as they being well versed in TPS/Lean to be able to inform personnel about all benefits with specific actions.

8.4.3 Demand variability

A fluctuating demand can risk the kanban buffert to not deal with peaks in demand for some lower-volume products. Therefore, the kanban card calculations use extra safety factors. It is, however, important for the kanban planner to continuously update the cards, especially in situations with predictable peaks in demand. In such cases, extra kanban cards can be initiated temporarily to prevent stock-outs in the supermarket. The long-term solution for such challenges is, however, heijunka, i.e. production leveling, which has some of this paper's constructs as prerequisites, such as setup time and batch size reduction. Therefore, heijunka is not part of this paper's scope.

8.4.4 New products

Another risk factor TePe faces, in general, is the rapidly growing difference between asset turnover and profit margin. This can be due to their strategy of continuosly introducing new products to the market. In average, TePe's new products increase unique articles of raw materials by 50-100 each year, leading to more tied-up capital, a more complex material flow, more changeovers of machines etc. An increase in machine changeovers, for example, leads to worse flow efficiency, which has an impact on asset turnover.

Chapter 9. Conclusions

This chapter summarizes the findings of the entire paper. The research questions are answered one by one, followed by this Master's thesis actual contribution to both practice and academia. Future development and research for both TePe and academia concludes this final chapter.

9.1 Conclusion

The main objective of this research has been to improve the materials supply processes to assembly lines in a manufacturing production facility through Toyota production system and Lean manufacturing, and recommend TePe on improvements in their expansion phase, based on three research questions. Through this paper, the constructive research approach has been used to produce these recommendations, or contructs, to practical challenges TePe faces, all based on theory. In collaboration with TePe management, we found three important aspects on what the research should be based, i.e. efficiency, safety and a new production facility. Since neither of these areas were specified in any precise detail, a comprehensive TPS/Lean process mapping was required as a foundation of the paper. Challenges were found, both in the mapping process but also as a result of the cross-case analysis, which guided the research to recommended constructs. Many of the challenges were, and are still, a consequence of an underlying focus on resource efficiency rather than flow efficiency. Research shows that this is a natural phenomenon in companies not aiming regular attention to TPS/Lean or production methods alike. Research also shows that a TPS/Lean implementation does result in a wide range of benefits for a company, even though several of them can be difficult to quantify in monetary terms. During this research, such challenges were encountered, why it is important for upper-management to really grasp the concept of TPS/Lean, and to *support* a full implementation before the actual one.

In the research of this paper, the ambition has been to letting the purpose and the research questions run through every chapter as a common thread. But as a reminder for the reader, the research questions are restated and answered below.

9.1.1 Research question one

How can materials supply processes to assembly lines be improved at TePe?

This research question expanded slightly over the months of this Master's thesis, since the actual materials supply processes were greatly affected by TePe's many different variants of toothbrushes, which, in turn, led to large amounts of tied-up capital and long lead times. This paper, therefore, *provides a systematic way of reducing setup times* by 57 per cent, leading to a 50 per cent reduction in tied-up capital and a 23 per cent reduction in lead times, which is illustrated in *Table 9.1*. This, in turn, leads to a positive yearly impact of 0.74 MSEK and a reduction of tied-up capital to a value of 3.7 MSEK.

Table 9.1. Some of the metrics reduced by an implementation of this paper's constructs.

Area	***Metric***	***Current state***	***Projected future state***	***Projected % improvement***
Efficiency (RQ1)	Total lead time	31 weeks	24 weeks	23 %
	Total process time	23.75 min	23.75 min	–
	Activity ratio	0.03 %	0.04 %	29 %

Giving TePe the opportunity to an increased number of changeovers, congestions in-between operations can be mitigated, leading to a better flow of materials to assembly lines. By also suggesting the *implementation of a kanban system*, this paper offers a structured replenishment procedure, leading to an overall visualization company-wise and a foundation for continuous improvements – *kaizen* – which has become *the* TPS/Lean catch-phrase over the last decades. In combination with an implementation of, what this paper calls, *managerial principles* and a *5S implementation*, not only can the materials supply processes to assembly lines be improved but the flow efficiency of the entire production facility. This paper's all constructs are presented in a PACE chart in *Figure 9.1* below, evaluating (1) execution ease against (2) anticipated benefit.

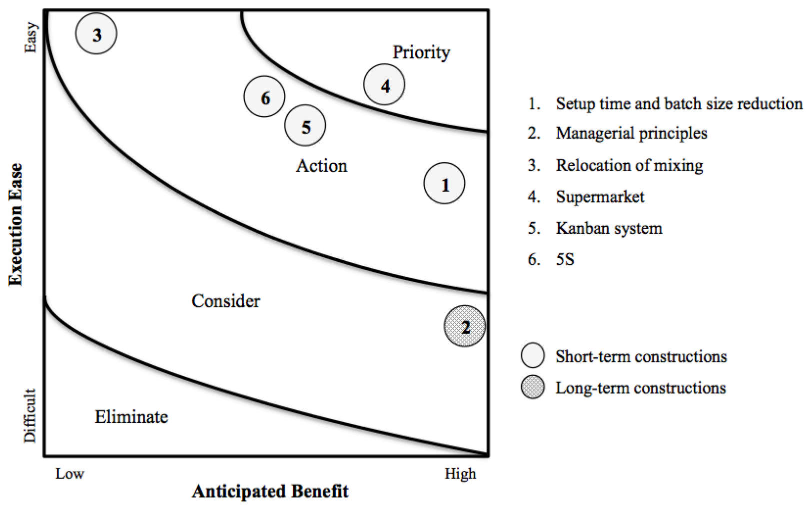

Figure 9.1. Evaluation of recommendations for TePe.

9.1.2 Research question two

How can safety hazards be minimized in materials supply processes at TePe?

The underlying challenge in terms of safety hazards at TePe has been a simultaneous movement of assembly/packaging operators and forklifts. The aim of this paper was, therefore, initially to minimize movement of either element, focusing on forklifts movement. However, with an implementation of both a supermarket and the kanban system, as well as a relocation of the mixing operation, *the elements can be separated altogether*. Consequently, the safety hazards are eliminated, which means that the actual distance traveled by forklifts becomes an irrelevant number.

9.1.3 Research question three

How should raw materials be supplied to the new production facility?

This research question is based on challenges of the new production facility being located on two different floors, connected by an elevator. By, on second floor, implementing a supermarket for raw materials, including a structured replenishment system through a *kanban system* within a *supermarket*, materials availability will always be high. Rather than improving the actual materials flow, these recommendations eliminate lost production to a value of several millions SEK due to in-house stock-outs. The recommended layout is presented in *Figure 9.2*.

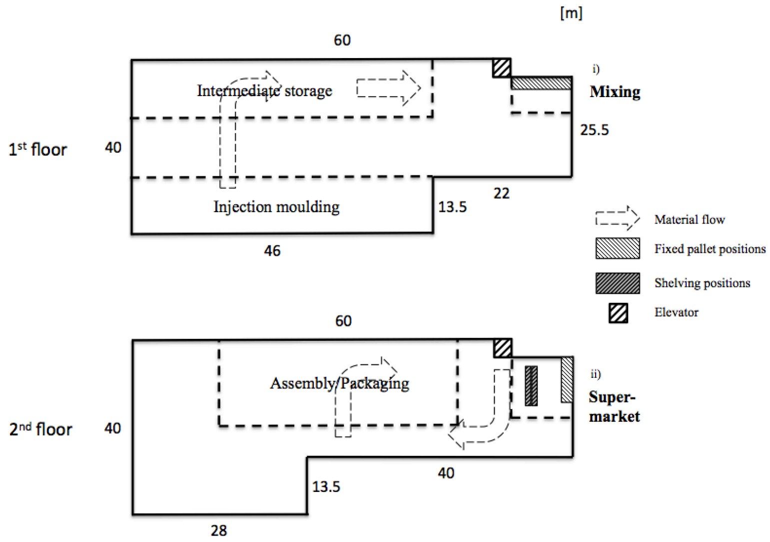

Figure 9.2. A possible layout for the new production facility for toothbrushes.

9.2 Contribution

There are also four main elements in the constructive research approach; one being the theoretical contribution. The constructive approach is, in fact, used regularly in Master's theses. This paper contributes to both academia and practice with yet another application of the constructive approach, but on materials flow tailored for a manufacturing firm. This paper can, therefore, either guide the researcher in using this same methodology in a practical case with similar characteristics, or guide the practitioner to, in a structured way, finding, and mitigating, challenges related to materials flow in any manufacturing company. This paper can be especially interesting for manufacturing firms which has not yet started implementing any specific production method, such as TPS/Lean, as it gives a theoretically hands-on approach for such an implementation, indicating many generic improvement possibilities.

This paper also manages to contribute to academia in a number of ways. A new TPS/Lean maturity model has, for example, been introduced, and practically used, after a comparison between five existing Lean maturity models. Such an explicit comparison has not been found elsewhere. For the stages of the TPS/Lean maturity model, see *Figure 9.3*.

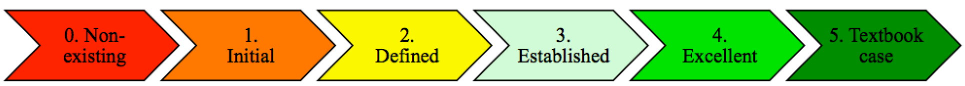

Figure 9.3. Stages in the TPS/Lean maturity model.

The maturity models have been compared based on Lean maturity levels, criteria and objective. In this new TPS/Lean maturity model, I have incorporated the time aspects related to the success of any Lean implementation, based on research by Ivarsson et al. (2018). Unlike the other models, this maturity model is also based on the TPS/Lean house. Another way in which this paper contributes to academia is by incorporating research by Modig and Åhlström (2012) into the TPS/Lean house, distinguishing between values, principles and methods. Finally, since the theoretical framework is a comprehensive summary of TPS/Lean, it can be used as a learning tool to understand the basics quickly.

9.3 Future development and research

Even though this paper contributes to both practice and academia, there are many areas in which either further development or further research is needed in each field.

9.3.1 TePe

This paper recommends TePe on implementing several constructs to mitigate some of their current challenges. Many of the constructs are, such as any TPS/Lean implementation, not a one-time-only activity but instead an activity based on continuous improvements over time. Therefore, TePe needs to sustain many of the responsibilities this paper suggests in an implementation. But there are also many areas in which TePe can seek further improvement opportunities once they have succeeded in implementing this paper's recommendations. Their high variability in demand is, for example, a great challenge in a logistics perspective. An investigation of a closer relationship to upstream suppliers could possibly reduce WIP in their raw materials warehouse, leading to even further lead time reductions. The same goes with downstream customers. A close communication can spread out peaks in demand, motivating for heijunka, production leveling, which is the aim when setup times are low enough. Another area in which TePe can seek improvement opportunities is by extending the T-kanban system into a dual kanban system to further reduce many of their challenges. Likewise, if TePe finds similar challenges in other product categories, except the toothbrush, an implementation of a similar T-kanban system may be beneficial in these areas. A concluding remark is on TePe's strategy of offering many different types of toothbrushes in a wide range of colors. This paper shows that for TePe to be profitable, they need to put more effort into improving the efficiency of the use of their assets rather than further on increasing their profit margin. A way of improving can be to re-evaluate their product offerings.

9.3.2 Academia

There are several examples mentioned above from which a researcher using the constructive research approach can proceed another case study research. This paper would, anyhow, have been strengthened further in terms of external validity if there was a multiple case study including several companies. Therefore, such an investigation would, with higher certainty, pinpoint how any degree of TPS/Lean implementation affects a company's overall performance in practice. Moreover, this paper assumes a TPS/Lean implementation to be superior other change efforts in terms of suitability for TePe. This can, however, be argued, since TePe also demonstrates characteristics, like many other companies, moving towards a more customised production with higher profit margins. A future research focus can, hence, be to investigate a development of this paper's TPS/Lean suggestions into more Leagile recommendations. It would be of great interest to, for example, study a postponement of product customization in any manufacturing firm, but especially in TePe's value stream.[55] Another future research focus would be to test and investigate this paper's TPS/Lean maturity model on several other cases, as well as critically assessing it against other Lean maturity models.

[55] One could consider studying the effects of postponing color differences in the value stream of toothbrushes. In a Leagile value stream, all toothbrushes would, for example, be injection moulded in a standard color. The agile value stream would start in assembly/packaging, in which the product is customized with a wide range of colors for filaments.

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Appendices

Appendix I: Workshop I

The participants in *Workshop I* can be seen in *Table 0.1* below.

Table 0.1. Information about Workshop I.

Information	***Participants***	***Number of participants***
Workshop I – Introduction and Discussion 20-01-20	Supply Chain Manager	1
	Production Manager	1
	Warehouse Manager	1
	Technical Manager	1

This workshop is held as a *mid-term focus group update* with some of the most essential employees from TePe in regards to this Master's thesis' purpose. The objective of the workshop is to inform the participants on how far the project has come, to discuss futher progression and to prepare them for *Workshop II*, in which they will evaluate the recommendations.

Approach

Workshop I starts with a presentation of *challenges* faced at TePe, this Master's thesis' *research purpose*, *research questions* and, shortly, about the *theoretical framework* and the *methodology* used. Here, it is emphasized that there is a multiple case study including companies that has been successful in using TPS/Lean themselves. By executing a cross-case analysis along with comparing TePe's specific case with research and theory, the recommendations will be based on both "best-in-practice" and the latest research. This is done to create some trust of the process in use. Then, the analysis so far is presented for the participants, for them to give feedback and also, for me, to verify gathered data and the analysis. This is followed by a discussion about how to proceed with the analysis to reach appropriate recommendations.

Discussions

The discussion is based on challenges, implementation and success factors. The discussion is, however, only semi-structured letting the participants discuss all aspects that come to mind.

Challenges

The *7 wastes* are discussed, in which the participants conclude that they lack in fulfilling to minimize several categories, such as *overproduction, excess inventory* and *unnecessary transportation.* Some specific challenges at TePe, which have been discovered through observations, are discussed, such as long lead times, long waiting times and long setup times, and what causes them. Large *batch sizes* is one, while *mixing colors* is another.

There is also a lot of transportation of raw materials, handles and toothbrushes in general, which is time consuming and resource inefficient. Moreover, there are bottlenecks in injection moulding as well as machines having quite some downtime, giving an unbalanced flow. In addition, *mixing colors* requires quite some space within the warehouse today, which reduces safety for both *assembly operators* and *warehousing operators.*

Moreover, challenges that TePe meet in their expansion phase with the movement of the production plant is discussed further. The materials flow to the second floor, where the *assembly* and *packaging* will take place, is the greatest challenge since there is only one elevator in which material can be transported.

Finally, there is also a discussion of the components in the *efficiency matrix* presented by Modig and Åhlström (2012), in which the participants agree on that TePe is far more *resource efficient* than *flow efficient*.

Implementation

Possible solutions that could solve some of the challenges TePe faces are briefly discussed. Since large batch sizes is a challenge, changing batch sizes from pallets into transportation boxes which fit 300 handles each is suggested, and the participants concurred that it is a solution worth investigasting. This goes in line with TPS/Lean, which encourages smaller batches, even though a *one-piece flow* is theoretically optimal.

Regarding long setup times, I mention a possible solution using *SMED*, which has been exemplified by Shingo (1984, p. 130) to reduce setup times in several cases into 1/10 to 1/60 of a machine's initial setup time. A participant addresses that there can be resistance to a tool alike from operators who have managed some machines for several years. But the participants also agree on it being a tool worth considering.

Lean tools such as the *pareto chart* and the *product family matrix* are discussed as well. The participants verify the idea of the project to be focusing on one high-volume product and one low-volume product to understand the materials flow of different products. However, there is suggested for me not to focus very much on the layout of machines in the new production plant since that is already prepared for. Instead, a recommendation which suits the challenges faced with the new production plant is of priority. Questions to consider in addition to the research questions:

- How is material going to flow from inventory to the assembly lines and back?
- How much material is needed for the assembly lines?
- Layout of intermediate storage?

Success factors

The majority of the participants agreed on success factors for the recommendations of this Master's thesis to be *simplicity* and *good assumptions*. These characteristics will most likely guide a future implementation of the constructs recommended, according to participants. Another success factor is for the recommendations to be based on illustrative analyses, such as the VSM presented during the workshop. The VSM clearly shows a *waiting time* of 7.5 months while the *processing time* is some 23 minutes. According to the production manager, it is important for employees to understand such a difference for them to accept a change.

Appendix II: Workshop II

The participants in *Workshop II* can be seen in *Table 0.2* below.

Table 0.2. Information about Workshop II.

Information	***Participants***	***Number of participants***
Workshop II – Evaluation of Recommendations	Supply Chain Manager	1
	Production Manager	1
	Warehouse Manager	1
	Technical Manager	1

This workshop is held as a *final feedback meeting* with some of the most essential employees from TePe in regards to this Master's thesis' purpose. The objective of the workshop is to present the developed constructs of this paper, for the participants to evaluate using the evaluation sheet presented below.

Evaluation sheet for developed constructions

This evaluation sheet has been developed in order for the researcher to understand the suitability of suggested constructs. Each participant in *Workshop II* evaluates the constructions using a three-levels rating system. After a short presentation of each suggestion, the participant types the corresponding letter into the chosen box/score. The rating system is presented below, and the form is illustrated in *Table 0.3*.

1. The suggestion should/will not be considered.
    a. The suggestion is not applicable to TePe.
    b. The suggestion does not work in practice.
    c. The suggestion probably worsen performance.
    d. The suggestion probably improves performance, but…
    e. Other reason.
2. The suggestion should/will be considered.
    a. The suggestion probably improves performance partially or marginally.
    b. The suggestion probably improves overall performance.
3. The suggestion should/will definitely be considered.
    a. The suggestion probably improves performance partially or marginally.
    b. The suggestion probably improves overall performance.

Table 0.3. Form to evaluate the developed constructions.

Suggestion	***Score***			***Comment***
	1.	***2.***	***3.***	
New production facility (RQ3)				
Supermarket				
Kanban				
Efficiency (RQ1)				
SMED				
Batch size reduction				
Safety (RQ2)				
Mixing elsewhere				
5S				

Are you satisfied with the results from this Master's thesis?	Not satisfied	Satisfied	More than satisfied

Evaluation of developed constructs

The majority of participants seemed satisfied with the developed recommendations thus far. There were a few suggestions on improvements, such as extending the number of kanban cards to be able to control some variability on demand. Out of the participants who finally filled out the evaluation sheet, all were certain about the *kanban system* and *mixing elsewhere* to definitely be considered, improving overall performance, with an average score of 3. The other constructs were evaluated to be either considered or definitely considered, with an average score of 2.5. Every participant was either satisfied or more than satisfied with this paper's results.

Appendix III: Case Study Protocol
I. Overview of the Case Study

1. Research Purpose:

The purpose of this thesis is to improve the materials supply processes to assembly lines in a manufacturing production facility through process mapping and lean manufacturing, and recommend TePe on improvements.

2. Goals:

The thesis provides TePe with a better understanding of their materials supply processes and suggests improvements in their expansion of the production facility. For academia, the results will clarify difficulties in having efficient materials supply processes to assembly lines in a manufacturing industry. For me, personally, I will learn a great deal about the subject and get some real-life experience from the industry along with better researching skills.

3. Unit of Analysis

The unit of analysis of the thesis is defined as materials supply processes to assembly lines in the production facility of a manufacturing company.

4. Research Questions

A. How can materials supply processes to assembly lines at TePe be improved through process mapping and lean manufacturing?

B. Why is the materials supply processes at TePe bringing safety hazards? How can these safety hazards be minimized?

C. How should raw materials be supplied to the new production facility?

5. Theoretical Framework:

The theoretical framework for this thesis is existing literature reviewed in the area of Lean manufacturing (LM) and Toyota production system (TPS). There are several must-reads in the literature, e.g. Schonberger (1983), Ohno (1988), Womack et al. (1990), Shingo (1984), Liker (2004) and Rother and Shook (2004).

II. Data Collection Procedures

1. Collecting Evidence

A. Direct observations[56]

- Spending a lot of time in the production facility
  - Ohno circle
  - Observe material flow, processes, the work environment, operators, buffers, stocks etc. to get an understanding, and look for possible *problems*
    - Ishikawa diagram
- Mapping and understanding the materials supply processes using *Lean* tools
  - VSM
  - Operation chart
  - Spaghetti diagram
  - Product families
  - Tied-up capital graph
- Finding *bottlenecks*
  - Calculate *annual capacity* in machines/processes
- Finding value-added and non value-added activities
  - Being prepared on theory
  - Mapping
- Measuring lead times of materials supply processes
  - Clocking warehouse operators when replenishing
- Measuring *takt time* and *cycle time* on a high volume and a low volume product
  - Clocking machines when operating
- Measuring amount of inventory in intermediate storing
  - # of pallet locations

B. Interviews

- Semi-structured
  - Key informants
    - Blue-collar workers
    - Production manager
    - Supply chain manager

[56] Key source of evidence.

        - Warehouse manager
    - Use funnel model presented by Voss et al. (2002)
        - Start broad – open-ended questions
        - Narrow down – more detailed questions
    - Send interview guide in advance
    - No recording
    - Apply *5 Whys* throughout interviews

C. Archival records

- Copies of maps and charts over production
- Copies of expansion area
- Sales volumes
- Data from machines
    - Down-time
    - Efficiency
    - Defects
- Data on tied-up capital, buffer stocks, lead times etc.

D. Documents

- List of relevant employees
- E-mails

E. Other sources of evidence exemplified by Voss et al. (2002)

- Informal conversations – field notes to increase reliability
- Attendance at meetings

2. Concepts for High Validity

A. Multiple sources of evidence

B. Field notes

C. Data base – transfer field notes, physical documents etc. to data base as soon as possible

D. Chain of evidence – link observations, interviews and conclusions

E. Triangulation

F. Pattern analysis – look for patterns

3. Case studies

A. Embedded design

B. Longitudinal at TePe

C. Purpose

- Discovery/Descriptive

- Mapping
- Cross-case analysis
- Constructive approach

D. Case selection

- "Two-case" case study – including TePe
- Manufacturing company in southern of Sweden
- Theoretical replication (aiming for the case company having implemented some lean methods)

III. Data Collection Questions

See *Appendix V*, *Appendix VI* and *Appendix X*, for interview guides for TePe management, TePe operators and Nolato management, respectively.

IV. Data Analysis

1. *Pattern matching*
   - A. Patterns between case/principal company and theoretical framework
   - B. Patterns based on Lean critical success factors
   - C. Patterns based on the lack/use of Lean tools
   - D. Causal relationships
2. *Within-case analysis*
   - A. Effects matrix
     - Lead time
     - Quality
     - Cost
     - Safety
     - Morale
   - B. Role-ordered matrix
     - Interviews and observations
3. *Cross-case analysis*
   - A. Meta-matrix
     - Context
     - Characteristics
     - Application
     - Success factors

- Challenges
- Barriers
- Improvement aspects

V. Timeline

An overall timeline of the paper is illustrated in *Figure 0.1*. For a more detailed version of time management of this paper, see *Appendix IV*.

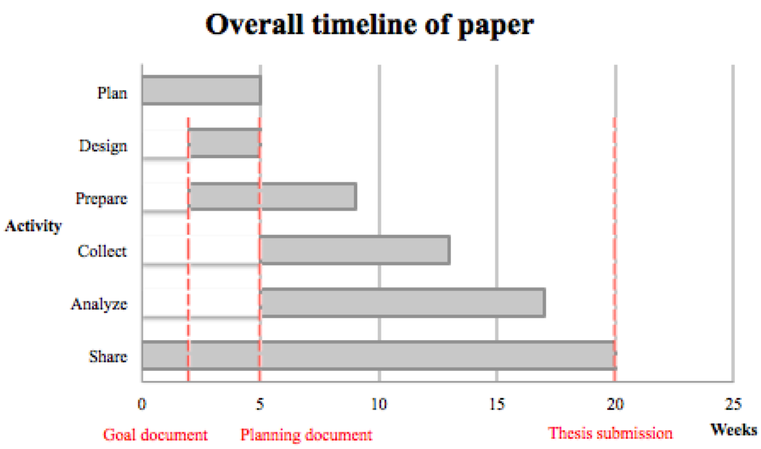

Figure 0.1. Overall timeline for project.

VI. Other

1. Audience for the report

A. Thesis *students* – therefore, quite descriptive regarding terms

B. Thesis committee

C. Practitioners (especially TePe)

2. Reporting format and illustrative structure

A. Multiple-case study based on Yin's (2014) format of a single-case study

B. Linear-analytic

Appendix IV: Time Management

Huberman and Miles (1994) discuss the *arithmetic* for a project, which basically is a detailed plan of the amount of days specific tasks will take. I designed a brief plan for this Master's thesis early on to get an understanding of up-coming work schedule. The plan is presented in *Table 0.4*.

Table 0.4. Timeplan för this paper.

<table>
<tr><th>Activity (phase)</th><th>Task</th><th colspan="2">Days</th></tr>
<tr><td rowspan="6">Plan</td><td>Introduction to problem at TePe</td><td>1</td><td rowspan="6">10</td></tr>
<tr><td>Specify research questions and scope</td><td>1</td></tr>
<tr><td>Meeting supervisor</td><td>0.5</td></tr>
<tr><td>Literature study</td><td>3</td></tr>
<tr><td>Goal document write-up</td><td>3</td></tr>
<tr><td>Extra time allocation</td><td>1.5</td></tr>
<tr><td rowspan="3">Design/Prepare</td><td>Literature study</td><td>7</td><td rowspan="3">15</td></tr>
<tr><td>Planning document write-up</td><td>7</td></tr>
<tr><td>Extra time allocation</td><td>1</td></tr>
<tr><td rowspan="8">Collect/Analyze</td><td>Observations and coding</td><td>6</td><td rowspan="8">67.25</td></tr>
<tr><td>Within-case analysis</td><td>20</td></tr>
<tr><td>Interviews</td><td>6</td></tr>
<tr><td>Observation and interview at case company</td><td>1</td></tr>
<tr><td>Cross-case analysis</td><td>20</td></tr>
<tr><td>Daily meetings</td><td>30 min. x 20 weeks = 6.25</td></tr>
<tr><td>Workshops</td><td>3 x 1 = 3</td></tr>
<tr><td>Extra time allocation</td><td>5</td></tr>
<tr><td rowspan="2">Share</td><td>Extra report write-up</td><td>5</td><td rowspan="2">8</td></tr>
<tr><td>Presentation and opposition</td><td>3</td></tr>
<tr><td>Extra</td><td>Vacation</td><td>15</td><td>15</td></tr>
<tr><td colspan="2">Total</td><td colspan="2">115.25</td></tr>
<tr><td colspan="2">Time available for thesis</td><td colspan="2">115</td></tr>
</table>

Appendix V: Interview Guide for Management at TePe

1. Background

Name ___________________________________

Job Title ___________________________________

Years in Position ___________________________________

Years with Company ___________________________________

2. Context

A. Is there a map over the production facility I could have a copy of?

- Can you guide me through the production process?

B. Are there any organizational charts (with contact information) I could have a copy of?

C. How do you work with *safety* in the production facility (in the *warehouse* and in *production*)?

- What safety hazards do you see today? Why?
- What safety precautions are taken from employees?
- Have there been any accidents recently? What, where and why?
- Do you measure *safety*? If yes, please explain how?

D. How do you measure *productivity* and *flow efficiency*?

- Do you have key performance indicators (KPIs) and, if so, which and for what?
  - Overall
  - Production
  - Assembly lines
  - Materials supply

3. Application

A. Has TePe implemented Lean production methods earlier?

- Are you familiar with the concept? Please, explain.
- Why did TePe choose to improve through kanban (lean production)? If *I do not know*, ask for someone who could answer.

4. Success Factors

A. What are the critical success factors of TePe in your opinion? Why?

5. Challenges

A. What are the main challenges today at TePe?

- Mention three major challenges.

- Why is it a challenge? (*5Whys*)
- What does your company do to overcome these challenges?

Note on possible challenges: Seven wastes? Long leadtimes? High inventory? Long setup times? People involvement? Customer dissatisfaction? Safety issues?

B. What are the key issues in *materials supply processes*, *efficiency* and *safety*? If several, please rank them. Use *5 Whys*.

Note: Long lead-times? High inventory? Long waiting time? Too much movement from employees? Expansion issues?

C. What are your suggestions on improvements?

D. What is the reason moving the production facility of TePe Toothbrushes?

E. Is there a concern moving the production process? Why is that?

Explanation: Due to the expansion, TePe chooses to move the production process of Toothbrushes to another area in the production facility to better utilize space.

6. Barriers

A. Are there any barriers to why you cannot implement *Lean principles* at TePe?

B. Have you ever "benchmarked" your production facility with other companies? If, yes:

- Which companies?
- What were the learnings/outcome?
- How did you implement it into your company?

7. Improvement Aspects

A. In which areas would you say that there are most improvement opportunities for your company? Why is that?

Appendix VI: Interview Guide for Blue-Collar Workers at TePe

1. Background

Name ________________________________

Job Title ________________________________

Years in Position ________________________________

Years with Company ________________________________

2. Context

A. Which task(s) do you perform? Please, explain the whole process from the point of input to output.

- What is the input to your task?
  - Material
  - Information
- What is the output of your task?
  - Material
  - Information

B. What equipment/tools do you use in your work?

- Do the equipment/tools have there own spot when not in use?
- Do you put any effort in having a clean workplace? Why, why not?

C. How many shifts are there for this process/machine?

D. How many operators are there at each shift working with this process/machine?

3. Challenges/Improvements

A. Are there any issues in general? If yes, what? Use *5 Whys*.

- What are your improvement suggestions?

B. Are there any issues specifically with *material*, *efficiency* and *safety*? If yes, what? Use *5 Whys*.

- What are your improvement suggestions?

C. Does your work stop at any point in time? If yes, when, where and how long? Use *5 Whys*.

D. Do you partake in any education at the company? If yes, which?

- Strategic (values, goals, teamwork)
- Operational (machines, efficiency, safety)

Appendix VII: Guide for observations

The following aspects are some essential ones to have in mind when observations are conducted:

- *Study work activities and value stream.* Barriers to flow? Bottlenecks?
- *Lead times.*
- *Waiting times*.
- *Processing times.*
- *Use Lean glasses everywhere based on theory.*
- *Lean tools*. Do they use or not use?
- *Batch sizes.*
- *Setup times.*
- *WIP.*
- *Storage.*
- *Layout.* What type of layout is it? Reasons for that?
- *Transportation times.*
- *Operators*. Unnecessary movement? Do they help each other? Any interuptions?
- *Inspections.*
- *Defects.*
- *Safety*. How does forklifts move in the warehouse? What regulations are set up?

Appendix VIII: Example of an initial e-mail to a case company

Hej [Namn på kontaktperson].

Jag är civilingenjörsstudent inom maskinteknik, specialiserad inom Logistik och Produktionsekonomi, på Lunds Tekniska Högskola. Just nu skriver jag mitt examensarbete inom TPS/Lean med uppgift att förbättra materialflödet hos TePe Munhygienprodukter i Malmö.

Examensarbetet är en flerfallsstudie, där företag som har implementerat principer och tankesätt kring Lean undersöks och analyseras. I och med att [Företagets namn] ligger i framkant här, och har vunnit bl.a. Lean-forums utmärkelse år [År], och dessutom har relativt hög kapitalomsättningshastighet, så är ni ett företag som är väldigt intressant för mig i min studie.

Jag är alltså intresserad av hur [Företagets namn] gör för att nå sitt mål att bli världsledande genom [Företagets egna produktionssystem], för jag antar att detta fortfarande är er filosofi trots att ni vann priset för ett antal år sedan nu. Jag skulle alltså vara intresserad av ett studiebesök hos er inom den närmaste framtiden om detta är möjligt.

Om du kan/vill hjälpa mig, eller om du kan vidarebefordra mig till någon av era Lean-koordinatorer eller produktionschef, uppskattas det mycket.

Tack på förhand!

Vänliga hälsningar,
Patrik Östlund

Appendix IX: Example of the following e-mail to a case company

Hej [Namn på kontaktperson].

Först och främst vill jag tacka för snabb respons!

Jag är alltså intresserad av exempelvis en halvdag, eller så mycket som hinns med, ute i [plats] för att förstå hur ni arbetar med [Företagets produktionssystem]. Det är av intresse att både hinna med en observation av produktionen och en intervju för att bl.a. uppfatta vilka lean-metoder ni använder, hur ni löser problem, hur materialet flödar etc.

Intervjun är indelad i *värden och principer, utmaningar, tillämpning av lean-metoder, framgångsfaktorer, barriärer* och *förbättringsaspekter,* och lägger extra vikt vid *flödeseffektivitet*, *säkerhet* och *hygien*.

Finns det möjlighet för en träff [Datum]? Jag kan vara tillgänglig alla vardagar. Annars mottages gärna andra förslag.

Du når mig här, eller via telefon när som helst: [Telefonnummer]

Er hjälp i projektet skulle uppskattas mycket!

Vänliga hälsningar,
Patrik

Appendix X: Interview Guide – Nolato

1. Background

Name ________________________________

Job Title ________________________________

Years in Position ________________________________

Years with Company ________________________________

2. Context

A. Industry – *Research beforehand*

B. Products – *Research beforehand*

C. Key customers – *Research beforehand*

D. How does the production facility look like?

- Is there a map over the production facility I could have a copy of?

E. How does the organization look like? How do you work with the organizational structure?

- Horizontal/Vertical?
- Are there any organizational charts I could have a copy of?

3. Application

A. What is Lean to you? Describe shortly.

B. How does your company work with Lean?

- Which Lean methods are implemented at your company? Use *Table 0.5* on next page.
- Mention the three most important for the success of your company.

Table 0.5. Guide for learning about which Lean methods are applied in the case company.

Principles	***Methods***	***Use***	***Used How/Other Methods in Your Company***
Jidoka	*Genchi Genbutsu*		
	Poka-Yoke		
	Andon		
	5 Whys		
	5S		
Just-in-Time	*Takt Time*		
	Continuous Flow		
	One-Piece Flow		
	Pull		
	Kanban		
	SMED		
People and Teamwork	***(Describe in last column)***		
Heijunka	***(Describe in last column)***		
Standardized Work	***(Describe in last column)***		
Visual Management	***(Describe in last column)***		
Kaizen	***(Describe in last column)***		
Other Lean tools	*Value Stream Mapping*		
	Ishikawa		
	Product Family Matrix		
	Pareto Chart		

C. How do you work with *safety* in the production facility (in the *warehouse* and in *production*)?

- What safety hazards do you see today? Why?
- What safety precautions are taken from employees?
- Have there been any accidents recently? What, where and why?
- Do you measure *safety*? If yes, please explain how?

D. How do you measure *productivity* and *flow efficiency*?

- Do you have key performance indicators (KPIs) and, if so, which and for what?
    - Overall
    - Production

4. Success Factors

A. Your company has been awarded for your Lean commitments. What would you say are your success factors?

- Mention three major benefits from implementing Lean.

5. Characteristics

A. Can you guide me through the *value stream* of an A-classified product (mostly sold)?

- What processes are *value added activities*?

B. How long are the *lead times* at an average?

- For A-classified products?
- For C-classified products (least sold)?
- How do you do to decrease lead times?

C. How much inventory do you have at this moment? Quantity/value?

- Raw material
- Finished goods
- WIP
- Buffer stocks
- Tied-up capital

D. What are the batch sizes?

- Are they customer-driven or standard?
- How do you calculate batch sizes?

E. How does your company handle *safety*?

- Which methods are used?
- Do you have any measurement for those?

6. Challenges

A. Have there been any drawbacks implementing Lean principles?

B. Did you meet any resistance from employees while starting to implement Lean principles?

C. What were the challenges before introducing *Lean principles*?

- Mention three major challenges.
- Why was it a challenge?
- What does your company do to overcome these challenges?
    - Possible challenges:
        - Seven wastes
            - Overproduction
            - Waiting time
            - Unnecessary transportation
            - Overprocessing
            - Excess inventory
            - Unnecessary movement
            - Defective products
    - Other

Note: Long leadtimes? High inventory? Long setup times? People involvement? Customer dissatisfaction? Safety issues?

D. What is your take on a company that has not implemented Lean principles?

- Any suggestions for such a company?

7. Barriers

A. What are the key issues/challenges today at your company?

- Mention three. Please, rank them.
- Why are those issues/challenges to you?
- How do/will you solve these issues/challenges?

B. Are there any specific issues/challenges in the material flow?

- In *materials supply processes*, e.g. Kanban?

C. Are there any barriers to why you cannot implement specific *Lean principles/methods*?

D. Have you ever “benchmarked” your production facility with other companies? If, yes:

- Which companies?
- What were the learnings/outcome?

- How did you implement it into your company?

8. Improvement Aspects

A. In which areas would you say that there are most improvement opportunities for your company?

- Relate to *7 wastes* and *Table 0.5*.
- Continuous improvement?

Appendix XI: Introduction

Introduction is used as a sort of *activity kickoff* to present the *value stream mapping charter*, but mainly to inform relevant employees about the objectives of the Master's thesis, the importance of their participation as well as expectations/fears. Basically, the introduction is held as a start-up of this Master's thesis at TePe. Participants are several blue-collar workers working where the chances of change are imminent. Since a cornerstone of TPS/Lean is *Respect for people and teamwork*, this introduction is an important start to set the foundation of the paper. The participants is presented in *Table 0.6*.

Table 0.6. Information about Introduction.

Information	***Participants***	***Number of participants***
Introduction and Discussion 25-11-20	Warehouse Manager	1
	Raw Materials Warehouse Operators	4
	Finished Goods Warehouse Operators	4

Approach and discussions

Introduction includes a brief presentation about the RQs of this paper and the methodology used. Moreover, there is a discussion about expectations and fears from the employees. According to several operators, a *critical success factor* for the new production area for toothbrushes (RQ3) is that there can be a good flow of materials without disturbances. Since the new production area have to be located on two separate floors, all materials need to be transported through an elevator. This is the greatest fear. Another success factor, taken from the *Introduction*, is *communication* between departments but also within departments.

Value stream mapping charter

The value stream mapping charter, which is suggested by Martin and Osterling (2014), prepares the VSM. The charter is presented in *Table 0.7* below.

Table 0.7. The preparation of the VSM.

Value stream mapping charter

Scope		**Accountable Parties**		**Logitics**	
Value Stream	*Materials supply processes in a production facility*	Warehouse manager	*Johannes*	Dates	*w. 48 and w. 49*
Specific Conditions	*One product: Toothbrushes (TB)*	Production leader, TB	*Ines*	Location	*On-site*
Demand Rate	*19,9x*10^6 *pcs/year*	Production planning	*Anette*	Briefing dates	*End of weeks*
Trigger	*Production planning*				
First Step	*Storing*	**Mapping Team**			
Last Step	*Processing (Assembly lines)*	Thesis author	*Patrik*		
Boundaries and Limitations in Recommendations	–				
Improvement Time Frame	*4 months*				

Current State Problems		**Measurable Variables**		**Benefits to Organization**	
1	*Efficiency*	**1**	*Lead time (time) and Processing time (time)*	**1**	*Increased sales*
				2	*Increased space utilization*
2	*Safety*	**2**	*Safety (# of accident reports/year or truck movement in time)*	**3**	*A more safe environment*

Appendix XII: Data on number of positions for SKUs in current production facility

The number of articles of raw materials and their location is illustrated in *Table 0.8* below.

Table 0.8. Fixed pallet and shelving positions for raw materials within intermediate storage (TEPE3 and TLIFT) and assembly/packaging (PROD3).

Article	***Pallet positions***		***Shelving positions***		***Number of articles***
	TEPE3	***PROD3***	***TLIFT***	***PROD3***	
Ankartråd	2	–	1	–	3
Batchfolie	–	1	–	–	1
Blisterbaksida	18	–	34	–	52
Blister Tray	–	1	–	–	1
Borst	8	2	16	–	26
Transportförpackning	–	4	–	–	4
Detaljistförpackning	–	7	–	–	7
Blisterfolie (GAG)	–	1	–	–	1
Etikett vit	–	–	–	2	2
Folie	–	–	13	–	13
Färgband etikettskrivare	–	–	–	1	1
Smältlim	–	–	–	1	1
Stämpelfolie	–	–	5	–	5
Tipp	–	–	2	–	2
Total	28	16	71	4	**119**
	44		**75**		

Appendix XIII: Brainstorming Session Using 5 Whys

The 5 Whys method was used during interviews to understand the root causes to any challenge. Each interviewee, then, tried to come up with relevant suggestions on improvement. When employees struggled to find any, I helped them be creative by giving examples. The majority of challenges (problems), which becomes the foundation of the Ishikawa diagrams in *Chapter 4.6*, are illustrated in *Table 0.9* below.

Table 0.9. Problems mentioned in interviews, their root causes using an alteration of 5 Whys and interviewee's suggestions on improvements.

Position at company	***Area***	***Problem Interviewee***	***Problem***	***Problem***	***Problem***	***Root cause***	***Relevant suggestions on improvement***
		Why?	***Why?***	***Why?***	***Why?***		
Operators	***Efficiency (RQ1)***	Complaints from management to production	Theoretically OK does not always mean practically OK	–	–	Collaboration between office and production	Management visiting production (Genchi genbutsu)
		A lot of administrative workload for FGW in materials handling	Double handling of information	–	–	Different ERP system in production and FGW	Shared ERP system
		Stressed occationally	Machine downtime	Stamp not in position Foil gets stuck in machine Manufacturing low-quality products	Machine changeover is problematic	Long setup times Long time before machines produce high-quality products after changeover	Educate technicians Operators help each others
		Pick up raw materials, which are not in position	No materials on shelfs	Call warehouse operator	–	ERP system	Raw materials closer to assembly lines Better replenishing system
		Pick up semi-manufactured goods, which are not in position		Walk to injection molding	*Handles* not finished in all colours	Machine capacity restraints in *injection molding*	Invest in new *injection molding* machines
		Visually checking if replenishments are needed	A lot of movement for operators	ERP system is not updated frequently	–	Unreliable ERP system	Put more resources into aligning to one ERP system

	Safety (RQ2)	Back pain	Bend while mixing	Heavy lifts while mixing	–	Not ergonomic workstations in *mixing*	Invest in a *mixing* machine Invest in a lift table
	New production facility (RQ3)	Material flow issues	Production on two floors	Elevator	–	Elevator is bottleneck?	Good planning Not moving production facility Update operators better
		Difficulties replenishing without paternoster lift	Production on two floors	Elevator	–	Elevator is bottleneck?	Good planning Shelving
Management	***Efficiency (RQ1)***	Overtime	Not meeting demand	Producing too few handles	Bottleneck in *injection molding*?	Machine capacity restraints in *injection molding*	Invest in new *injection molding* machines
		Materials supply processes not efficient	Operators picking same article number from different shelfs	Not standardized	–	Operators not educated Material too far away	Implement a Kanban system
		Increased demand	Difficulties meeting production plan	Do not want many machine changeovers	Long setup times, machines down and problems after machine changeovers	Unskilled technicians	Educate or invest in technicians
		Congestion in assembly lines	Variability in input	Reliability in machines in previous steps	–	Collaboration between operators	Educate/Incentives for operators to collaborate Automate all production steps
		Incorrect information in ERP systems	Defective waste in-between operations	Operators may not be commited	No control over material flow	Many articles	Implement tracking system Develop a better materials supply process

		Operators picking same article from different pallets	Articles spending more time in intermediate storage	–	–	Employee's not educated	Educate personell
Management	***Safety (RQ2)***	Safety hazards for operators	Forklifts moving	Operators picking raw material in warehouse	–	No signs or crossings for operators or visitors	Sign and crossings for operators and visitors
		Safety hazards for visitors		–	–		
		Broken secondary packaging	Forklifts colliding with secondary packaging in aisles	Operators not putting away secondary packaging properly	–	Operators picking and putting away raw materials in RMW	Educate operators Signs and painted lines Restrict movement of operators in the warehouse Kanban system
	New production facility (RQ3)	Material flow issues	Production on two floors	Elevator	–	Elevator is bottleneck?	Install an extra elevator assigned for raw materials only Kanban system Install paternoster lift
		Move all machines	No information about where the machines will be located	–	–	Poor information sharing	Better information sharing

Appendix XIV: Annual Capacity Calculations

If solving *Equation 1* (see *Chapter 2.17*), for D_i, and expressing CAP_j in available machine hours, an operation's capacity can be calculated. This final equation is illustrated below.

$$D_i = \frac{CAP_j * U_j}{t_{ij} + \frac{s_{ij}}{Q_i}} \quad (2)$$

where D_i = possible production of product i (pcs per time unit)

CAP_j = capacity in operation j (time units)

U_j = utilization of operation j

t_{ij} = processing time for product i in operation j (time units per piece)

s_{ij} = setup time for product i in operation j (time units)

Q_i = batch size for product i (pcs)

There are many assumptions made due to TePe's wide product portfolio, affecting resource capacity calculations greatly. Therefore, these calculations should be used as guidelines rather than an actual truth. Assumptions made is described below, and summarized in *Table 0.10*.

Table 0.10. Assumptions for calculating TePe's annual capacity.

	Workdays	***Shifts***	***Machines***	***Takt time [s]***	***Utilization [%]***
Injection moulding	330	3	14	14	80
Assembly/Packaging	260	2	10	4	

Injection moulding is totally automated and runs almost every day, 24/7, except for some holidays and weekends. The availability in days for injection moulding (330) is, therefore, estimated to be slightly higher than assembly/packaging (260). Takt times are based on observations and, are an estimated average for all products in an operation. The actual setup times are estimated by technicians to be around 120 minutes (see *Appendix xx*), and, therefore, that value is used on the outset. Finally, the annual capacity is multiplied with an 80 per cent utilization factor to account for break-downs and both planned and unplanned shutdowns.

Appendix XV: SMED Calculations and Implementation

There is a possibility of reducing setup times remarkably both in the short- and long-term by implementing SMED to TePe's injection moulding machine park. The following pages evaluates the possibilities of such an in-depth SMED implementation and gives some general advice before an implementation.

Today, a changeover of an injection moulding machine at TePe in average takes 118 minutes, including 20 general steps. This SMED evaluation is based on estimations from technicians assessing average and maximum number of minutes completing each task of a changeover. As foundation of the analysis is the average value. The final aim is, then, to convert as many IEDs to OEDs to reduce the actual setup time. This paper's SMED analysis is further divided into three implementation stages with different results, requiring different effort, time and cost from TePe. The estimated time reductions for each task and stage is illustrated in *Table 0.11* below, followed by brief explanations of each reduction.

Table 0.11. Setup time for injection moulding machines, and possible time reduction if SMED is implemented.

Task (Step)	***Actual net time [min]***		***SMED***					
			Stage 1		***Stage 2***		***Stage 3***	
	Av. [min]	***Max [min]***	***Type***	***New av. [min]***	***Type***	***New av. [min]***	***Type***	***New av. [min]***
Retrieve/find/clean new mould (1)	5	15	OED	0	–	0	–	0
Retrieve overhead crane (2)	2	5	OED	0	–	0	–	0
Attach overhead crane (3)	4	10	IED	4	IED	3	OED	0
Retrieve/find Allen keys (4)	5	10	OED	0	–	0	–	0
Disconnect water and heat (5)	1	3	IED	1	IED	1	IED	1
Loosen bolts (6)	15	20	IED	15	IED	6	OED	0
Remove mould from machine (7)	5	10	IED	5	IED	4	IED	1
Loosen overhead crane (8)	2	5	IED	2	IED	2	OED	0
Attach overhead crane (9)	4	10	IED	4	IED	3	OED	0
Move mould into machine (10)	5	10	IED	5	IED	4	IED	1
Tighten bolts (11)	15	20	IED	15	IED	6	OED	0
Loosen overhead crane (12)	2	5	IED	2	IED	2	OED	0

Connect water and heat (13)	1	3	IED	1	IED	1	IED	1
Leave overhead crane (14)	3	5	OED	0	–	0	–	0
Leave mould (15)	3	5	OED	0	–	0	–	0
Leave Allen keys (16)	1	5	OED	0	–	0	–	0
Retrieve/find/setup new color granules (17)	5	10	OED	0	–	0	–	0
Purge old color out (18)	5	30	IED	5	IED	5	IED	5
Loading/adjusting program (19)	5	60	IED	5	IED	5	OED	0
Inspection/Run machine to no defect (20)	30	975	IED	30	IED	10	IED	1
Unexpected problems (21)	0	20	OED	0	–	0	–	0
Total	**118**	**1236**	–	**94**	–	**52**	–	**10**
Total reduction [%]	–	–	–	**20.3%**	–	**55.9%**	–	**91.5%**

Advance preparation (Stage 1)

The first implementation stage includes a conversion of task 1, 2, 4, 14, 15, 16 and 17, which all have to do with preparation while the machine still runs. Since a changeover is planned days in advance, a responsible technician should be able to always prepare relevant tools and materials before a changeover is performed. This stage requires some planning of up-coming machine changeovers, distribution of machine responsibility for technicians, a short session to educate the technicians in the importance of preparation, as well as a 5S implementation. For a technician, a 5S implementation helps him finding relevant tools, since they are placed in a specific area. Right before a changeover, everything needed should be perfectly placed in order of action next to the machine (Shingo, 1984). That is not the case at TePe. An implementation would result in short-term setup reductions by around 20 per cent for a low investment cost. At first glance, the reduction may seem great for the effort invested. But Shingo (1984) states that by only focusing on performing OEDs while the machine runs, the setup times are often reduced by 30-50 per cent.

Standardization (Stage 2)

The second implementation stage does include the previous stage, but also a presumed reduction of time spent on other tasks, such as task 3, 6, 7, 9, 10, 11 and 20. This stage builds upon standardizing the changeover with a setup sheet and rely on, and work for, continuous improvements.

No indepth SMED analysis has been implemented in this paper, and, therefore, it is difficult to assess how tasks like *attach overhead crane (3 and 9)* and *move mould into/from machine (7 and*

10) can be improved specifically. However, these tasks, which takes more than two minutes to perform today, are assumed to be reduced by 20-25 per cent through continuous improvements.

Loosen bolts (6) and *tighten bolts (11)* are tasks that can be performed with two technicians working in parallel, reducing time spent with up to two thirds (Shingo, 1984). By being innovative, there are probably more tasks that can be performed working in parallel.

A great challenge for TePe in the changeover process is not the actual setup, but the time between a finished setup and manufacturing non-defective products. This can be seen in *inspection/run machine to no defects (20)*. A color change often influence the color of new products. In fact, there is often at least one transportation box with around 300 handles scrapped after a setup due to discoloration. This means a value of 1 243 750 SEK annually. Once, not long ago, a setup at TePe actually used 13 full transportation boxes before producing non-defective products. It is, therefore, important to create standardized work procedures even for color changes. Colors should, for example, always be changed from brighter spectrums to darker spectrums, which is not the case today. An investment in purging compounds to clean moulding machines is also recommended. The purging compound can be used when going from darker spectrums back to brighter spectrums. By taking these actions, this step is estimated to be reduced by two thirds in the long run.

Finally, each product requires its unique machine program for specifications such as injection speed and cycle times. This is already implemented at TePe, and, therefore, *loading/adjusting program (19)* is difficult to reduce further. However, the machine program for each product should be updated regularly.

An implementation of this stage is predicted to reduce setup times by 57 per cent in the long-term. This may seem incredible. But companies applying SMED in average reduce their setup times by 95 per cent (Shingo, 1984). Over a year, Mitsubishi Heavy Industries, for example, reduced setup times from 24 hours to two minutes and 40 seconds, and Toyota Motor reduced theirs from eight hours to 58 seconds.

Investment costs

An engineer educated in SMED, advisably the production manager, is estimated to work full-time with the project for two to three weeks to create a proper setup sheet. Every technician needs to participate in the change. The technicians are estimated to put two full days of work each into the project, including (1) helping creating the setup sheet, (2) brief education in the importance of kaizen and (3) discussions for improvements. This means wages to a value of 100 000 SEK.[57] The project is estimated to involve approximately six employees.

There are some other investments required as well. Purging compound is estimated to cost 10 000 SEK yearly.[58] Even smaller initial investments may be needed, such as recording equipment and a 5S implementation.

Since SMED is an ongoing improvement project, the initial implementation phase is part of a longer improvement phase, in which technicians need to strive for continuous improvements (see *Chapter 7.5* for kaizen). Evaluating and updating the setup sheet and striving for improvements need to be embedded in the work of both the engineer and each technician.

Some advice

An engineer should have the overall responsibility of the SMED implementation. However, the technicians know the machines and the changeover process by heart and they are, therefore, vital in constructing the setup sheet. Primarily, the actual net time for a changeover needs to be clocked meticulously. This is most successfully achieved by recording the changeover, for the technicians to watch themselves afterwards. Watching oneself in the work environment provides objectivity and new improvement aspects (Shingo, 1984). Then, it is important for the engineer to organize discussions between the technicians. Discussion begets ideas for time reductions, and if the ideas come from technicians themselves the sense of belongingness increases as well as productivity.

The setup sheet should contain quite detailed information about the changeover. For example, this includes expected time spent on each task, an operation manual with information about each task, which tools/materials needed and where to find them etc. The setup sheet needs regular updates through continouos improvements.

Both the engineer and the technicians, then, need to use their ingenuity in the process of constantly reducing setup times. *Chapter 2.8.5* supports with some theoretical suggestions on general improvement ideas. Some questions to ask is presented below to inspire the investigators.

Are bolts actually needed to fasten the mould, or is there a more time-efficient solution? Bolts are, for example, often longer than necessary, which leads to excessive tensioning. Investigate the real function and purpose of the bolts, as well as minimum clamping force. Are all tools and materials in perfect order next to the machine during a changeover? Why not? Are tools/moulds functionally standardized for all products? Are standard fixtures used? How much of the actual tool attachment can be prepared before a changeover? Can, for example, other bolts be attached in the

[57] 40 000 SEK for a full-time engineer working two to three weeks, and 60 000 SEK for five technicians working two full days.

[58] Based on annual sales of 19 900 000, batch sizes of 14 400 and a 40 SEK cost per purge, with a purge every sixth changeover.

new mould beforehand? Are operator and tool movements minimized during the changeover? Use 5 Whys to understand root causes.

Appendix XVI: Supermarket layout and implementation costs

The supermarket layout, as is presented in *Figure 0.2* below, is primarily based on raw material article data and kanban calculations (see *Appendix XVIII*). To decrease unnecessary tied-up capital, a shelving system is beneficially established in the supermarket. The shelves should be located as close to the elevator as possible, as for minimizing transportation distances. However, an advice is to maintain a passage between the wall and the shelves to ease accessibility.

According to the kanban calculations, 28 pallet positions are needed for bulky raw materials in the supermarket. An advice is to invest in a three floor racking system to decrease space usage. The pallet positions are not included in the kanban system, since it is easy for warehouse operators to see for themselves if a replenishment is needed. Eight out of 36 pallet positions are assigned mixed toothbrushes from mixing and finished toothbrushes from assembly/packaging. All mixed toothbrushes being assembled/packaged during the day are located in the racking system for assembly operators to pick up. With today's batch sizes, eight pallet positions are sufficient since the machine park consists of ten machines and a batch takes approximately 20 hours to manufacture[59]. This is similar to the current layout at TePe.

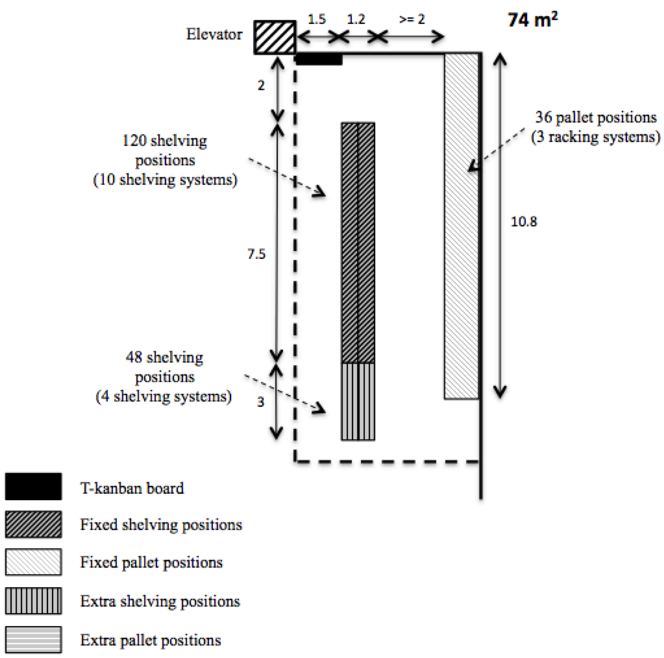

Figure 0.2. Supermarket layout.

Implementation time and investment costs

For kanban implementation together with shelving investments, see *Appendix XVIII.* A three-floor racking system needs, however, to be purchased and installed in the supermarket. The installation is estimated to take between two days and maximum a week for two employees. The investment costs,

[59] Based on a takt time of five seconds and a full pallet.

however, are what is estimated to be costly. A three-floor racking system containing twelve pallets are estimated to cost 5 000 SEK, which gives a total of 15 000 SEK. Since the supermarket is located on the second floor, and no forklifts fit in the elevator, investing in a manual pallet stacker is a necessity. A manual pallet stacker is estimated to be purchased for 10 000 SEK. Not investing in a racking system would put all pallet positions on the floor, making the supermarket more than twice as big. This would interfere with the assembly/packaging area in future expansions, leading to barriers in expanding.

Appendix XVII: Extending the Kanban System

There are two opportunities to extend the kanban system in the future. On the one hand, a P-kanban system can, and should, be investigated when this paper's other recommendations have been implemented and the results have been achieved. On the other hand, the physical kanban system can be extended into partly an electronic kanban system in the future. However, none of these opportunities have been investigated due to several reasons mentioned below.

There are many reasons why TePe should examine a dual kanban system, extending with P-kanban cards for toothbrushes. TePe will, for example, be able to better manage their inventory levels for toothbrushes (i.e. reduce tied-up capital), increase flow efficiency, place more control in the hands of the operators, but most importantly, creating an orderly and highly visual system in the entire production facility, which increases self-improvements. Many of the reasons are, however, difficult to quantify, and this paper has not tried estimating the positive effects due to time limitations. Another factor of not investigating the P-kanban system is the need of short setup times and small batch sizes in order for such a system to be beneficial. Therefore, TePe needs to decrease both of them before evaluating a P-kanban system. Moreover, TePe also needs to evaluate customer collaboration to decrease variability in demand before implementing such a system. In fact, research shows that the standard deviation on customer demand should not exceed 30 per cent of average customer demand (Shingo, 1984; Olhager, 2013). At times, that same standard deviation reaches 100 per cent at TePe.

A physical kanban system can seem to be unnecessary and a waste of time for an operator. After a few months, the assembly/packaging operator may stop moving the kanban cards to the kanban board, forcing the warehouse operators to check each shelving position, which creates annoyance. Therefore, it is important to avoid this scenario by informing employees about the advantageous with the kanban board: everything related to raw materials is visible for anybody at any time. With that said, it is important to keep the physical cards, but the registration of orders can be simplified with, for example, finger scanners to scan barcodes instead of being registered manually.

Appendix XVIII: Kanban Card Calculations

The storing positions within the supermarket are based on the results presented in *Table 0.12* below. The first column presents article categories and the amount of unique articles. Every unique article needs a unique storing position. Based on the size of articles, they are, then, either stored on shelves or pallets; bulky articles are stored on the latter. *"SKUs per position"* is the actual number of SKUs stored on a "full" position, based on kanban calculations. This column also tells what type of container a SKU is, such as a box or a roll. *"# of kanban cards (max. WIP levels)"* presents the total number of T-kanban cards suggested for the article category, which are also the maximum number of SKUs-in-process. The last column is the basis for the fixed quantity kanban system, since it suggests the quantity when an article is to be replenished, i.e. the *"safety stock"* in the kanban system of that article. For all articles, the safety stock is always at least a day of demand. The attentive reader sees that an article such as "borst" has an extra high average demand, and, therefore, needs more kanban cards (see row seven in *Table 0.12*). These articles has a demand of 1-3 boxes daily, which increases both kanban cards and the safety demand. Altogether the suggestion is to implement an initial kanban system for 113 unique articles with 227 kanban cards. The pallet positions are excluded.

Table 0.12. New production facility's pallet positions and shelving positions within the supermarket.

Article (unique)	***Supermarket***		***Container***	***SKUs per position***	***# of kanban cards (max. WIP level)***	***Safety stock (per article)***
	Pallet positions	***Shelving positions***				
Ankartråd (3)	–	3	Roll	3	9	1
Batchfolie (1)	2	–	Pallet	1	2	1
Blisterbaksida (52)	–	52	Box	2	104	1
Blister Tray (1)	2	–	Pallet	1	2	1
Borst (22)	–	22	Box	2	44	1
Borst (high volume, e.g. 10022, 10028, 10091, 10016) (4)	–	12	Box	2	24	3
Transportförpackning (+tråg) (4)	8	–	Pallet	1	8	1
Detaljistförpackning (SRP + 4-, 25- och	14	–	Pallet	7	14	1

100-pack) (7)						
Blisterfolie (GAG) (1)	2	–	Pallet	1	2	2
Etikett vit (2)	–	2	Piece	*"several"*[60]	4	2
Folie (13)	–	13	Roll	2	22	1
Färgband etikettskrivare (1)	–	1	Piece	*"several"*	4	2
Smältlim (1)	–	1	Piece	*"several"*	4	2
Stämpelfolie (5)	–	5	Roll	2	10	1
Tipp (2)	–	2	Box	1	2	1
Total (119)	**28**	**113**	–	–	**227**[61]	–

[60] The article is small and space restrictions are no problem.
[61] Pallet positions are not part of the kanban system.

Appendix XIX: Practical Information About the Kanban Implementation at TePe

Before an implementation of a kanban system is possible, some preparations must be made. The following sections discuss these preparations/projects, namely: (1) T-kanban cards, (2) the kanban board and (3) the shelves. Each project also has an estimated time allocation and investment cost. Note that the time allocations are rough estimations, only to be able to roughly evaluate investment time and costs. Also not that if the kanban system in the future is extended to a dual kanban system, including P-kanbans, new preparations/projects similar to the following are needed.

T-kanban cards

Every unique article needs several physical kanban cards, which means 219 T-kanban cards in total (see *Appendix XVIII* for Kanban card calculations). Every card needs basic information about (1) the article, (2) storing locations, (3) container size and (4) WIP. *Figure 0.3* is an illustration of the type of information a card for an article at TePe can contain. A suggestion is to use different colors for different article types, e.g. all ”borsts” are blue, all ”blisterbaksidor” are green etc., which increases transparency.

Time allocation

This project is suitable for the warehouse operators (or the warehouse manager) to carry out, since they are knowledgeable in this area and will use the cards in their everyday work. Participation and teamwork in general generates enthusiasm and dedication to a common goal, and increases productivity. The project of gathering and structuring information, as well as printing and laminating the cards are assumed to take two days for two employees.

T-kanban

Borst 0060 32 mm NC410
Art. nr.: *10022*
Storing pos.: *Shelving A33*
Container: *Box*
From: *TePe 3*
To: *Supermarket* Card: *3/4*

Figure 0.3. An example of a transportation-kanban at TePe.

Kanban board

The kanban board should have room for at least 113 card holders, such as hooks, racks or magnets, for the kanban cards to be stored. There are several examples on the Internet. Every hook needs information on article name or number and the amount of cards to initiate a replenishment (see Kanban calculations). The investment costs are negligible in relation to shelving investments, and are, therefore, not predicted.

Time allocation

This project includes selecting and purchasing a kanban board with card holders, as well as attaching the board in the supermarket. The delivery time is the most influential factor, since the other operations are done in a few hours.

Shelves

All unique articles being part of the kanban system need a shelving position. Some articles obviously have different sizes. But for all types of articles to fit a position based on this analysis, the position needs the following dimensions: $d = 0.6$, $h = 0.6$ and $b = 0.5$. The suggestions of this paper is built on shelving systems that have the following dimensions: $d = 0.6$, $h = 1.8$ and $b = 1.5$, and have four shelves. This means three unique articles per shelf, and twelve articles per shelving system. There are many shelving systems on the market, however, they need to be designed for production facilities and able to cope with heavy material. An example of a simple shelving system is pictured in *Figure 0.4*. In total, 10 shelving systems are needed for all 113 articles within the kanban system. However, based on TePe's aim on future expansion, TePe management guided this paper's recommendations to consist of 14 shelving systems.

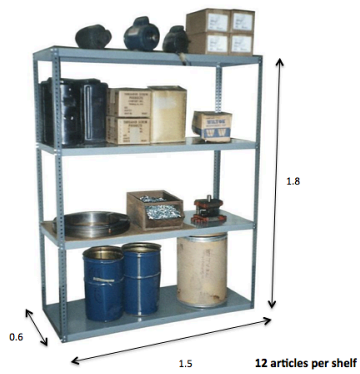

Figure 0.4. An example of a shelving system. Adapted from Vistamation (2020).

Every shelving position needs the article name and a marked area for those articles. Moreover, every position needs a kanban card carrier (akin to a brochyre holder) in front of or next to each position. If there, for example, are three boxes of an article on the shelving position, there should be three T-kanban cards for that article in the card carrier.

Finally, each unique article needs to be assigned a position. An advice is to name the shelving systems A, B, C etc., and the positions 1, 2, 3 etc., which makes it easy to find and understand the system. For example, all ”borsts” can be stored in shelving system A and B, while all ”blisterbaksidor” can be stored in shelving system C, D, E etc. The storing position for a unique ”blisterbaksida” is, for example, named C3.

Time allocation

This project includes selecting and purchasing both shelving systems and card carriers. Those need to be installed within the supermarket. Shelving positions need to be named and assigned articles, as well as painted. If three to four employees work with the project, it is assumed to take one week. An advice is that the warehouse operators and/or assembly/packaging operators are involved in the implementation of this project, since they are affected on a daily basis by the end result.

Roles and responsibilities

Abovementioned preparations need project manager(s), who delegates responsibility to appropriate personnel. An advice is to give the *warehouse manager* the overall responsibility of the kanban implementation. He delegates the responsibilities of establishing kanban cards, the kanban board and shelves. If further alterations in the supermarket layout is required, he has the responsibility of collaborating with personnel responsible for the overall layout of the new production facility.

The kanban system also needs a *kanban planner*, whose responsibility is to update the system regularly. In more detail, this means to (1) update (and cut) the kanban buffer, (2) do follow-ups on potential stock-outs, (3) do practical checks on cards, shelves and the replenishment process, (4) introducing new articles to the system if needed etc. Note that a kanban update does not mean theoretically *calculating* new card numbers, but instead withdrawing a card from the system. An update can be illustrated with a simple example. The kanban planner detects a shelving position often being full. She simply withdraws a T-kanban card together with the raw material being attached to the card, and informs the warehouse operators about her decision. If no stock-outs occur due to the withdrawal, the card is permanently discarded.

Note that the position of kanban planner is not a full-time job, but a part-time responsibility over the time a kanban system is used. Since the kanban system is a link between RMW and assembly/packaging, the role of kanban planner can also, and is advisably, divided onto two employees, one from each operation/department. By communicating over departments, many hidden challenges will arise to the surface. An advice is to have short regular briefing meetings about the kanban system. Initially, this means daily meetings, but can be decreased to weekly meetings after the first four weeks.

Time allocation

A kanban planner needs to be somebody well-versed in the production, with some knowledge about Lean/TPS. This can either be personnel from management, who applies genchi genbutsu to a great extent, or a team leader or operator within the production facility. An advice is to promote an operator to such a position pushing responsibility down the corporate ladder, to increase a sense of belongingness and productivity as well as to initiate continuous improvements all around the company.

The kanban planner's presence is most important over the first four weeks of the kanban implementation due to her work of monitoring the materials flow and adjusting any unforeseen issues, such as stock-outs of an article. The workload of the planner ease over time, even though she needs to do monthly checks on the system. Note that the position of kanban planner is not a full-time job, but merely a responsibility over the time a kanban system is used.

Implementation time and investment costs

Abovementioned projects all need to be carried out before an implementation of the kanban system is possible. However, many of the projects can be executed in parallel. A rough estimation is that an initial implementation of the kanban system requires no more than two weeks. Since TePe moves their production facility in the kanban implementation process, the opportunity costs of not manufacturing any toothbrushes is zero. Therefore, implementation time per se does not cost TePe anything. However, employee wages are difficult to estimate since nobody is full, or even half, time employed in any specific project. The wages are estimated to be low. Instead, the purchasing costs of materials are the most influential factor affecting investment costs. A shelf system is assumed to cost 3000 SEK, leading to a total investment cost of 42 000 SEK. By adding supplements and employee wages, a budget of 60 000-80 000 SEK for the entire kanban implementation would be sufficient.

Appendix XX: 5S Implementation

The project of implementing 5S can be divided into two phases: (1) the actual implementation of 5S and (2) sustaining 5S. Implementation time and costs as well as responsibilities are briefly discussed below with some advice.

The actual implementation of 5S

Implementing 5S at TePe is seen as a low-cost investment. The project requires an employee, who has the overall responsibility at each department. This is advisably either a manager or a supervisor. There are two intrinsic parts of the project.

First, the manager/supervisor guides the process of every operation evaluating tools needed. All tools can, for example, be gathered in one place, and if some tools are not used for a longer period of time they are discarded. The necessary tools are, then, given a specific location, such as on the wall or on a board to visually display which tools exist and are available. There are several examples of such arrangements on the Internet. Such an investment is vital especially for injection moulding, since it facilitates for a setup time reduction.

Second, each operator needs to meticulously clean and organize their work environment before photographing the workplace. Cleanliness provides a safe work enviroment as well. The photos need to be printed and laminated, and, then, placed next to each workplace.

Implementation time and costs

The arrangement of visually displaying tools is seen as a small investment, probably only a couple of thousand SEK. It is estimated to take a maximum of two days to gather tools and prepare the board/wall. Organizing workplaces is estimated to take a few hours per employee. Adding the preparation of photos, it is estimated to take three days with little materials cost. The project includes every workstation within an operation (e.g. injection moulding, assembly/packaging, warehouse etc.), and, therefore, between 5-20 employees, who have responsibility for their own workstation. Including both operators and the manager/supervisor, the entire project is estimated to require a full-week salary for one employee, i.e. 20 000 SEK.

Sustaining 5S

It is harder to sustain a 5S implementation than it is to actually implement it. The employee needs to systematically go through step one to three (i.e. sort, set in order, shine) every single day to keep the new standards in place (10-15 min each day). Therefore, it is important for the manager/supervisor to support, as well as educate, the employees in the process. As a starter, education and follow-ups on 5S can be integrated into the weekly meetings at TePe. It is important that the manager/supervisor is well-versed in 5S, and its effects, such as, according to Olhager (2013) are, better efficiency, higher quality, better visibility, less movement etc. Every change process starts with the management being willing to change.

There needs to be at least two follow-ups, one after a few weeks and another after a few months to evaluate how well 5S is sustained. The process of sustaining 5S does not require any investment per se, but instead an incorporation of 5S as part of the culture and a habit at TePe (see *Chapter 7.3* for managerial principles). To continuously improve over time, smaller projects can be performed as well, such as peer reviews for employees to ensure that defined schedules are being met. Other commitments, such as cleaning schedules, working schedules etc., should also be evaluated and updated over time.