International Master of Industrial Management

Title:

Value Stream Mapping for SMEs: a case study

Author:

Daan Smits

Academic Master Thesis

Royal Institute of Technology

Tutor: Professor Thomas Sandberg, KTH

7th edition, 2010 – 2012

Amsterdam, June 15th, 2012

Abstract

Due to a changing competitive environment, SMEs have to improve their production performance. A commonly applied philosophy to improve production performance is called lean thinking. This method, derived from the Toyota Production System, banishes wasteful activities while increasing the competitive strength and responsiveness of a company.

Many companies fail in their attempt to become lean and therefore techniques are needed to guide the implementation. This thesis proposes to use Value Stream Mapping as an implementation technique for SMEs. This technique is tested in a company as a case study. By applying the Value Stream Mapping tool to a specific process within this company, substantial improvement potential is revealed. Work content can be decreased by 30,3 percent, and delivery time and in-factory lead time can be decreased by at least 38,6 percent and 68 percent respectively.

The thesis concludes that lean thinking is applicable to SMEs, at least under certain circumstances. Furthermore, Value Stream Mapping can be a valuable tool in revealing improvement potential.

Personal Experience and Acknowledgement

During my studies, two questions regarding lean thinking came up which I have tried to answer ever since. First, how can an existing organization start to become lean? Second, is lean thinking only for large organization, or can it also be applied to smaller companies? Writing this thesis has given me the opportunity to understand more about the combination of these two questions. The knowledge and experience I gathered during my academic career came together in this concluding piece of my studies.

Above all, this research allowed me to experience lean ‘in real life’. I have long sought to personally connect what I learned in the classroom to a practical situation in which human emotions and behaviors play an important role. From an outsider’s perspective, I was able to see how employees complain about their managers and how managers complain about their employees complaining about them. I saw, and tried to deal with, people who resisted change even when the quantitative analysis supporting change was overwhelming. On the other hand, I experienced how both managers and employees took genuine steps to reach out to improve the relationship. Where some people were stubborn, others, sometimes unexpectedly, were eager to learn and enthusiastic to change their working habits. On top of this all, I finally learned to solder, to connect electric and pneumatic systems, and to use a grinder. At least to some extent. This unique experience already has proven to be very valuable in the rest of my career, and will continue to be so in the future.

I want to thank Wouter and Maarten for allowing me in their company and for having faith in my work. André, thank you for showing me around an supporting me along the way. Special thanks go out to all the employees of Wheels Inc., for being open and honest about their work and for answering all my questions. I wish all of you the best for the future.

Gratitude to the IMIM consortium, for offering this great opportunity. The past two years have been a life changing experience. Thanks to all my amazing friends from around the world. I wish you well and hope we will meet again and again. Also, I want to thank professor Sandberg for guiding me during the past semester.

Finally, I want to thank my parents for supporting me in many ways all these years. Without their help and guidance, none of my experiences would have been possible. Thanks to my girlfriend, for always being there, even at a distance.

CONTENT

LIST OF ACRONYMS

FIFO	First In First Out
GM	General Motors
IMVP	International Motor Vehicle Program
JIT	Just In Time
MRP	Manufacturing Resources Planning
NNVA	Necessary Non Value Added
(N)NVA	Necessary Non Value Added and Non Value Added
NUMMI	New United Motor Manufacturing, Inc.
NVA	Non Value Added
SME	Small and Medium Enterprise
SMED	Single Minute Exchange of Dies
TOC	Theory Of Constraints
TPS	Toyota Production System
VA	Value Added
VSM	Value Stream Map(ping)
WIP	Work In Progress

1. INTRODUCTION

The current competitive, economic, and global nature of international markets presents companies with a changing set of competitive ‘rules of the game’, to which they have to adhere. For ‘Western’ companies, this means that their historically dominant position is threatened by players from upcoming markets. Especially production companies have felt this pressure increasing over the past decades. Three trends in particular force Western production companies to improve their competitiveness; globalization, demanding customers and the current economic downturn.

Globalization

The trend of a globalizing world economy forces Western companies to increase their competitiveness. A couple of decades ago, companies mainly competed with competitors based in the same region. Decreased costs of intercontinental transport combined with a gap in labor costs between different regions lead to the increased viability of relocating production capacity to low cost countries. Not only did Western companies start producing their goods elsewhere, a great number of new competitors, from upcoming countries, entered the global market. The surge of these new competitors clearly shows in, for example, the Fortune 500 list. Only a decade ago, USA based companies occupied 185 places on the list, which is now down to 133. Similarly, twelve Chinese companies could be found on the list in 2011, versus 61 in 2001 (CNNMoney, 2011).

An important way for Western countries and companies to compete is to increase productivity. In the Western region, the workforce barely grows, making it difficult to increase output by increasing the employee base. This is especially the case in Western Europe, where the workforce is expected to remain stable (Bisson, Stephenson, & Viguerie, 2010). As a result, GDP growth should be generated by improving productivity. More than two thirds of productivity growth has historically come from product and process innovation. By increasing productivity, the labor cost per unit decreases, making the company more competitive. As such, the increased competition is a reason for companies to rethink their manufacturing processes (Goh, 2006).

Demanding customers

The second trend is that customers become more demanding in terms of delivery time and customization and that demand for (variations of) products changes rapidly (Stock, Greis, & Kasarda, 1999). Customers expect their products to be delivered faster and faster. Companies could achieve this by keeping stock of products, which can be delivered instantly. However, increasing levels of product customization prevent this strategy from being beneficial. Companies would have to keep inventory of such a variety of products, which greatly increases holding costs. Holding costs as a percentage of inventory value spans a wide range, depending on the industry, but averages between 10 and19 percent, and around 40 percent of these costs are accounted for by obsolescence (Timme & Williams-Timme, 2003; Wilson & Delaney, 2001).

A more attainable and economically viable method to decrease delivery times of highly customized products is to decrease the levels of work in progress (WIP). Little's Law states that the time a product spends in a steady state process is linearly correlated to the amount of WIP and the average interval at which products come out of the production process (Little, 1961). Decreasing these parameters directly leads to shorter delivery times, which makes a company more responsive to customer demand. The description of Value Stream Mapping (VSM) (Rother & Shook, 2003) will make clear that it is generally easiest to decrease WIP levels.

Economic downturn

The current economic downturn has a strong negative influence on most world economies. In the Netherlands especially the industrial sector encounters negative pressure (Rabobank, 2009). The downturn forces companies to decrease costs to cope with decreased demand, and to meet stringent working capital requirements as financial institutions become more strict. Both can be reached by decreasing WIP levels. First, lower WIP levels leads to less required working capital, since working capital equals current assets minus current liabilities, and WIP is considered to be a current asset. Second, a lower level of WIP decreases costs as this leads to lower holding costs, as described earlier.

Effects on Small and Medium Enterprises

These trends also affect an important group of companies, Small and Medium Enterprises (SMEs). SMEs are defined as companies with less than 250 employees, and less than €50 million of revenue or a balance sheet total less than €43 million. This group of companies represents an important part of the European economy. 99 percent of businesses in the European Union are SMEs, over two thirds of private sector jobs are found SMEs, and SMEs account for more than half of the value added in the European Union (European Commission, 2012).

Research shows that SMEs are strongly affected by the economic situation (Dun & Bradstreet, 2011). SMEs have relatively little negotiating power with their customers and suppliers concerning payment conditions in order to improve working capital levels and prices (Manoochehri, 1988; Porter, 1979). Their problems with working capital lead to financing issues, since they have little negotiating power with their lenders (especially banks) and banks are currently not keen on increasing credit facilities for companies.

The combination of the three described trends and the large effects these trends have on SMEs, leads to the conclusion that SMEs need to improve their processes in order to survive. This is especially relevant for the European economy, due to the important fraction of businesses, jobs, and added value SMEs are responsible for.

Improving production processes

A popular method for large companies to improve production processes is to engage in implementing the Lean production philosophy (Hopp & Spearman, 2008). This methodology, derived from the Toyota Production System, focuses on eliminating wasteful activities, categorized in seven types of waste: Transportation, Inventory, Movement, Waiting, Over-processing, Over-production and Defects. Literature on lean manufacturing presents tools to identify these wastes as well as countermeasures to deal with the wastes. Research shows that the implementation of lean manufacturing can lead to significant improvements in overall performance indicators, such as productivity, quality and delivery lead time (Zimmer, 2000). This concept was developed in Japan after the Second World War, because at that time, Japanese manufacturers did not have the possibility to make the large investments needed to compete with manufacturers based in the United States. Their competitive advantage thus needed to be based on increasing productivity with lower investments.

The road to becoming lean can be full of obstacles and many companies fail in their attempt (Sohal & Egglestone, 1994). This is described in abundant research, especially concerning large companies. The implementation of lean in SMEs received less attention in the academic literature. As this philosophy may yield positive results in large companies, it is interesting to understand if it is applicable to SMEs to a similar extent and this will be the focus of this thesis.

This thesis proposes to use a technique, called Value Stream Mapping (VSM), as a starting point for SMEs to become more lean, and thus more productive and competitive. The VSM technique first describes the entire process of the becoming of a specific product (family). Through a series of questions, the technique then guides towards a proposed future state. In the future state less time should be spent on activities which do not add value to the product. This technique has a number of favorable characteristics to apply it as an implementation method. First, it is a well tested and relatively simple technique. Furthermore, VSM presents its findings in comprehensive, visual representations of a value chain. This is key in the involvement of higher management. Finally, it gives an indication of what lean tools are applicable for the specific process of the company. This final advantage is of great importance, because lean manufacturing offers a vast variety of tools and companies have problems to identify exactly what tools are needed and how they should be implemented (Pavnaskar, Gershenson, & Jambekar, 2003).

The purpose of this thesis is to understand if VSM is indeed a useful method for SMEs to become more productive and to serve their customer better. Subsequently, the research question is:

Does Value Stream Mapping offer a valuable guidance in the quest of SMEs to become more productive and to increase responsiveness to customer demand?

The sub research questions comprising the main research question are:

(a) Is the lean manufacturing philosophy applicable to SMEs?
(b) Is VSM the most appropriate tool to initiate lean in SMEs?
(c) Does VSM reveal sufficient improvement potential for SMEs?

Sub research questions A and B will primarily be investigated by means of an extensive literature review. The methodology section of this thesis will describe the approach to sub research question C.

Delimitations of this research

This thesis will focus on companies classified as discontinuous flow line manufacturing systems, derived from the framework of Hayes and Wheelwright (1979). According to Lasa, de Castro, and Laburu (2009), a great portion of lean research focuses on these companies. They also state that lean tools have shown great impact in this type of companies and therefore this thesis will limit to the lean philosophy. Other productivity improvement methods, such as Theory of Constraints (TOC) (Goldratt & Cox, 1984) or Total Quality Management are outside the scope of this thesis. As the lean philosophy is primarily associated with manufacturing, this thesis will focus on manufacturing elements. Finally, this thesis will focus on companies with productivity and lead time concerns, since lean was originally intended to tackle such problems (Ohno, 1988).

2. Literature Review

In this literature review first the history of lean manufacturing, its most commonly used tools, and the results which can be achieved by implementing lean will be elaborated upon. Then, the applicability of lean manufacturing in different fields and types of companies will be discussed. Finally, the methods of implementing lean manufacturing are covered which results in the hypotheses of this research.

2.1. Lean manufacturing

This section will give an overview of the history of Lean and the Toyota Production System (TPS), its most prominent tools and finally the results which can be achieved through implementing lean thinking.

History

After the second World War Japan suffered from high costs of raw materials due to a lack of resources. This made Japanese companies less competitive on the global market. Toyota recognized that in order to compete, they needed to "(…) produce better quality goods having higher added value and at an even lower production cost than those of the other countries" (Sugimori, Kusunoki, Cho, & Uchikawa, 1977, p. 553). Normally, this would call for the implementation of mass production techniques, which dominated the industry at the time. Eiji Toyoda, head of the Toyota Company at the time, was indeed determined to become a mass producer. This would require acquiring expensive production means which were specialized at producing large batch sizes of products. These large batches were necessary to spread the large investment over enough products, and to deal with lengthy setup times. However, the relatively small home market of Japan, combined with capital constraints, initially prevented Toyota from setting up such a mass production facility (Holweg, 2007).

Apart from financial and economic restrictions, Toyoda also recognized some major, structural flaws in the mass production methodology. To be competitive, mass producers aim to benefit from economies of scale. To reduce unit setup and machine costs, they generally produce in large batches of identical products which work their way through the production facility. As a result, "(…) parts spend most of their time waiting in queues rather than in being actually processed" (Karmarkar, 1987, p. 410). In concurrence with Little's Law, this results in longer lead times.

This 'batch and queue' method is problematic for a number of reasons. By elongating the time period between fabrication of a part and its use in a following process step increases the risk of loss or deterioration while it also increases the time between fabrication and possible feedback about quality. Furthermore, the level of safety stocks grows more than proportionally with lead times, since the safety stocks have to protect against longer lead times as well as greater variability in forecasts due to a longer prediction horizon. Finally, long lead times decrease a company's competitiveness due to distant due dates and make companies less responsive to customer demand (Karmarkar, 1987). Indirectly, the batch and queue method makes the producer incapable of delivering the product diversity demanded by consumers (Holweg, 2007).

Toyota recognized what they had to do: make low cost, low waste, high value products by combining different production techniques into a system which would produce a wide mix of products with low volume per product variety. An important person in the quest of Toyota to reach this was Taiichi Ohno, who joined Toyoda Spinning and Weaving in 1932 (Holweg, 2007). To decrease cost, Toyota put a severe focus on the elimination of waste, which is "(…) anything other than the minimum amount of equipment, materials, parts, and workers (working time) which are absolutely essential to production are merely surplus that only raises the cost" (Sugimori et al., 1977, p. 554). High quality should be attained by decreasing batch size, since Ohno had recognized that large batches, amongst having other effects, resulted in high number of defects (Holweg, 2007).

Over a span of several decades, starting in the 1950s, Toyota slowly developed its production system. According to Fujimoto (1999), the production managers at Toyota (such as Kiichiro Toyoda, Taiichi Ohno, and Eiji Toyoda) combined elements of a mass production system with their own ideas. Some believe that Toyota 'invented' a new production method, but actually it took some decades to become the Toyota Production System (TPS) as it became known to the rest of the world (Holweg, 2007).

It might sound trivial that the 'secret' of Toyota is eliminating all the process steps which do not add value, but studying the Toyota Production System more closely reveals some insights about how fundamentally different it is from traditional manufacturing views. All workers in Toyota factories are allowed to stop the line they are working on if they find a defect, by pulling a cord next to their working station. Also, every employee at Toyota has the right, and is encouraged, to make improvements to the production process (Sugimori et al., 1977). This is different from traditional plants, where special teams implement improvements and where extensive quality controls check for defects at the end of the line. All employees at Toyota learn to make improvements according to the so called Scientific Method. When employees see a problem, they try find the root cause and a countermeasure which copes with this cause. Before they implement the countermeasure they make an hypothesis about the effect of the countermeasure. Finally, they compare the actual to the predicted effect and investigate the possible difference. As such, they aim to truly understand not only the problem, but also the solution (Spear, 2004). The hypothesis based improvement process makes it ‘scientific’.

Understanding the Toyota Production System

TPS was first not understood by Western companies and academics and the superiority of TPS was sometimes bluntly negated. Holweg (2007) gives a clear insight in the development of understanding Toyota’s production methods and this will be elaborated upon next.

The first barrier to understand TPS was that it was not documented before 1965, when it was communicated, in Japanese, to Toyota’s supplier network. At this point, Toyota had already started a steady increase in market share. During the 1970s concerns amongst Western producers about Japanese imports rose. In 1980, 22,2 percent of personal cars sold in the United States came from Japan. Trade agreements were instituted to restrict the number of imported cars. Toyota worked around these restrictions by setting up assembly plants in the United States.

It was clear that Toyota had some competitive advantage, but at first this was attributed to external factors in favor of Toyota. Explanations varied from favorable wages and exchange rates, to support of the Japanese government and cultural differences. These explanations were eagerly supported by industry representatives, but some researchers, such as Abernathy, Clark, and Kantrow (1981), understood that the competitive advantage was mostly explained by superior manufacturing practices. In 1985 the International Motor Vehicle Program (IMVP) started to investigate why Japanese companies were outplaying Western companies and how large the gap was. The IMVP was a research program focused on the automobile industry, consisting of researchers from all over the world, based at the Massachusetts Institute of Technology.

A major breakthrough in accepting the superiority of TPS was instigated by a collaboration between Toyota and General Motors (GM), called the New United Motor Manufacturing (NUMMI) joint venture. In this joint venture, initiated in 1984, Toyota and GM reopened a former GM plant to produce cars of both brands. After the first year, the productivity at the NUMMI plant was more than 50 percent higher than the productivity level at another GM plant which was technologically similar. Also, the NUMMI plant had the highest quality standards of all GM’s U.S. plants. Under Toyota's leadership, labor input per vehicle was reduced to 19 hours, down from 36 hours previously. Defects dropped from 1,5 to 0,5 per 100 vehicles, and absenteeism decreased from 15 percent to 1,5 percent. NUMMI achieved these results without great changes in used technology and by hiring mostly the same workforce of when the plant closed in 1982 (Krafcik, 1986). This convinced the industrial sponsors involved in IMVP, of the fact that Toyota's true advantage did not lay in factors such as culture, but in its production philosophy.

From TPS to Lean

John Krafcik, one of the academics working for IMVP, was the first to use the term 'lean production' (Krafcik, 1988b). 'Lean production' is a more generic term for the principles instituted in TPS. According to Liker (1997, p. 481) lean is "(...) a philosophy that when implemented reduces the time from customer order to delivery by eliminating sources of waste in the production flow". Elliot (2001) states that the three basic principles of the lean philosophy are flow, harmony (pace set by customer demand), and synchronization (pull flow). He argues that these three principles should be present throughout the entire organization. Numerous authors, such as Turfa (2003) and Vasilash (2000), emphasize that lean manufacturing is not a tactic, but should be viewed as an endless journey a company embarks on. Finally, Ohno (1988) remarks that apart from the critical focus on eliminating waste, respect for humanity was equally important.

Lean and TPS are similar, but not the same. According to Hall (2004) key differences between lean and TPS are in the focus at the start of the process, the source of the solutions and the level of standardization. TPS usually starts with optimizing each separate (sub) process to achieve (close to) zero defects and therefore takes a detailed perspective in the beginning, before optimally linking the steps together. Lean starts with a broader view, looking at the entire process and identifying main sources of waste, which often occur at the boundaries of processes. Lean generally focuses on the implementation of tools, coming from a predetermined set of tools, to eliminate waste. These implementations are more likely to be driven by staff, which prevents employees to increase their problem solving skills. TPS focuses strongly on employee skills and allows countermeasures to problems to evolve more organically. Finally, it seems that TPS emphasizes more strictly on the standardization and documentation of work methods. This allows them to continuously 'test' if the work methods are adequate or can be improved.

Lean Tools

Around 101 different tools mentioned in the academic literature can be identified (Pavnaskar et al., 2003). Based on works of different authors, such as Shah and Ward (2003), Detty and Yingling (2000), and Bhasin and Burcher (2006), a selection of most common tools was made to be discussed here.

5S

This method aims to improve work area efficiency by strictly selecting what material is essential at a certain workstations. This material is given a specific location close to where it is required. Non-essential materials are placed on less prominent locations. In the translated version, the five 'S's stand for Sort, Straighten, Shine, Standardize, and Sustain. The 5S methodology is aptly summarized by the following statement: "A place for everything and everything in its place" (author unknown) (cited in Mastroianni & Abdelhamid, 2003).

Kaizen

Kaizen is the Japanese expression for "improve for the better". It is the daily effort to constantly improve the process of a company. Origins of wasteful activities are identified and sought to be eliminated. On top of the daily effort, special Kaizen events, called Kaikaku events (Womack & Jones, 2003), can lead to more breakthrough improvements. In such events, a specific process is studied in great detail to achieve more substantial improvement.

Just-in-Time (JIT)

By producing products and parts 'just in time' it is ensured that only the necessary amounts of products and parts are produced (Sugimori et al., 1977). Furthermore, parts arrive to the process where they are needed at the right time and are placed in the order in which they are needed. This decreases the amount of waste associated with excess inventories .

Single Minute Exchange of Dies (SMED)

In order to be able to produce in unitary batches with the flexibility demanded by the customers, it is essential to have extremely short change-over time. A great advancement in change-over reduction was achieved by Shigeo Shingo, who was hired as a consultant at Toyota (Holweg, 2007). His method studies the process of a change-over with great detail and identifies wasteful activities and activities which can be performed while the machine is running. Eliminating or relocating these activities can reduce change-over times from hours to minutes.

One of the tools often mentioned in combination with lean is Six Sigma, a method developed at Motorola and made famous by the implementation at General Electric (Klefsjö, Wiklund, & Edgeman, 2001). It is a method to identify and eliminate variability in a process and has the goal to improve quality. This method is especially useful when the source of defects and variability is not apparent (Kumar, Antony, Singh, Tiwari, & Perry, 2006). Due to the strong statistical analyses required, Six Sigma projects are lead by specially trained professionals. Research shows that the most effective way to improve processes is to implement a combination of lean and Six Sigma tools, often termed Lean Sigma (Smith, 2003). Most companies combining lean and Six Sigma start by improving their process with lean tools.

This eliminates a large fraction of errors and waste, but chronic problems might still exist. These chronic problems are then attacked by Six Sigma tools (Kumar et al., 2006). As implementing Lean Sigma starts with the implementation of lean, also for this combination it is relevant to understand how to start with lean.

It should be emphasized that lean is more than just the tools, and should be seen more as a philosophy. For Toyota, none of its tools are key to its production system. It sees the implemented tools as countermeasures to problems not yet solved. Tools are not viewed as solutions, because that would imply a permanent fix (Spear & Bowen, 1999). For instance, counter to popular belief, Toyota does have inventories of parts and subassemblies. These inventories are countermeasures to the problem that transportation time from supplier to assembly line is still higher than zero seconds and that no supplier can guarantee infinite quality and reliability. Many companies trying to imitate Toyota's production system have focused on the tools, instead of on the principles. This may lead to a production system which is rigid and inflexible and, possibly more important, does not evolve and improve to cope with changing external factors (Spear, 2004).

Effects of lean

According Soriano-Meier and Forrester (2002), the real benefit of lean stems from strengthening the entire system. Lean methods ensure that shortcomings of the systems reveal themselves quickly by the profound influence they have. This should trigger a quick response of the company to eliminate the shortcomings. The effect of this approach already became apparent in the early research on Toyota's production performance. Comparisons with other factories clearly showed the superior performance statistics (Sugimori et al., 1977). Later, Lathin and Mitchell (2001) claimed that traditional mass producers should be able to reduce their lead time by 90 percent and inventory levels by 90 percent, and increase labor productivity by 50 percent.

Case study research showed substantial improvement potential as a result of lean practices as well. Åhlström (1998) reports a case where 85 percent reduction in the number of defects, 94 percent reduction of manufacturing lead time, and 50 percent reduction in sales lead time are achieved. Another case is described by Abdulmalek and Rajgopal (2007). They report a potential of reducing production lead time with 70 percent of and work-in-progress levels by 90 percent.

These statistics are taken from a variety of companies with little information of the initial state of the companies. Therefore, they have little predictive value of the improvement potential for any given organization contemplating a lean initiative. Then again, achieving a fraction of these substantial improvements could already be attractive for many companies.

On the other hand, various authors have expressed skepticism about the lean approach. Critics claim that success statistics of lean are overstated either due to neglecting unsuccessful lean efforts (Allen, 1997; Timco, 2001) or by overly attributing improvements to partial conversion to lean (Needy et al., 2002). Furthermore, some authors question if lean leads to long lasting competitive advantage (Hayes, Pisano, Upton, & Wheelwright, 2005).

Other critique on the lean approach concerns employee wellbeing. Some research reports that production employees encounter intensified work pace without gaining autonomy (Landsbergis, Cahill, & Schnall, 1999). Others even accuse companies such as Toyota of dangerous conditions for workers and accident cover-ups (Mehri, 2006). These reports are contradicted by other research, which claim that even though work pace is high in lean environments, conditions are within an acceptable range (Adler & Cole, 1993). Some of this research even describes contradicting results for the same facility, for instance the well known NUMMI cooperation. Fervent supporters and early practitioners of the lean approach even claim that respect for people is an essential element of the approach (Emiliani, 2009; Ohno, 1988). The opposing findings limit a conclusive answer to the question if the lean approach has a positive or negative effect on employees. An extensive survey showed that the effect on employees is determined mostly by management behavior, not by an intrinsic effect of the lean approach (Conti, Angelis, Cooper, Faragher, & Gill, 2006).

In summary, by implementing lean thinking in an organization substantial results can be attained in terms of lead time reduction, efficiency increase and quality improvements. If managed correctly, this approach can also have a positive effect on the workforce.

2.2. Applicability of lean

The applicability of the lean philosophy in other countries, industries, and company sizes was questioned from the moment it revealed itself to the world outside Toyota (Womack, Jones, & Roos, 1990). This section will investigate the applicability of lean to different conditions.

Country specific conditions

When confronted with early studies about Toyota's production performance, various Western researchers and automotive industry representatives negated the intrinsic advantage of Toyota's system (Holweg, 2007). Given explanations, some even in official hearings (HMSO, 1978), revolved around country specific advantages, such as favorable exchange rates, cultural differences, and government policies.

With hindsight these explanations were inadequate, but they were reasonable at the time. Toyota itself believed that their production system was particularly ample in dealing with external issues specific to the Japanese economy and in capitalizing on traits specific to Japanese workers (Sugimori et al., 1977). Furthermore, Toyota indeed had the benefit of, for instance, a supportive government (Abernathy et al., 1981). Possibly, the proposed explanations where relevant enough to use them as a protection from accepting another's superior thinking.

As time passed, it became clear that the Toyota Production System, rather than Japanese roots, was the source of Toyota's competitive advantage. A convincing example of Toyota's foreign success is their cooperation, NUMMI, with General Motors. Other Japanese companies, like Nissan and Honda, have proven to be unable to match Toyota's standards (Spear & Bowen, 1999). Furthermore, Prabhu (1992) showed that lean thinking also offers benefits for non-Japanese companies located outside Japan. Voss (1995) claims that lean thinking has now become implemented across Western industries.

Industry specific conditions

The lean philosophy was developed in an environment strongly focused on manufacturing. As it is often termed "lean manufacturing" or "lean production" it seems to keep the connotation of being applicable only to production environments. However, vast amounts of research have shown the benefits attainable by applying lean to service environments. Examples are call centers (Piercy & Rich, 2009), healthcare institutions (de Souza, 2009), car repair shops (Womack & Jones, 2005), software development companies (Poppendieck, 2007) and universities (Hines & Lethbridge, 2008). Another non-production field in which lean is becoming increasingly relevant is the activity of developing new products (Hines, Francis, & Found, 2006).

Conversely, there are some industry conditions which can impede the use of lean thinking. Lee (2002) devised an “uncertainty framework” which indicates what type of strategy is most suitable for (members of) a supply chain, shown in figure 1. The horizontal axis represents demand uncertainty. Low demand uncertainty has characteristics such as predictable and stable demand, long product life, low profit margins, and low product variety. Conversely, products with high demand uncertainty have variable and unpredictable demand, a short selling season, high profit margins and high product variety. Supply uncertainty is found on the vertical axis. Supply chains with low supply uncertainty show less quality problems, more sources of supplies, more reliable and flexible suppliers, and a more mature production process than supply chains with high supply uncertainty.

Supply Uncertainty \ Demand Uncertainty	Low (Functional Products)	High (Innovative Products)
Low (Stable Process)	Efficient supply chains	Responsive supply chains
High (Evolving Process)	Risk-hedging supply chains	Agile supply chains

FIGURE 1: UNCERTAINTY FRAMEWORK, LEE (2002)

Lee argues that only members of a supply chain with low supply and demand uncertainty should pursue an efficient, or lean, supply chain strategy. If there are uncertainties in the supply chain, these should be eliminated by uncertainty reduction strategies, before a supply chain can become lean. If uncertainties cannot be sufficiently reduced, a different supply chain strategy should be selected.

To summarize, the literature shows that lean thinking can be used in a wide variety of industries. However, some external factors might prevent (a member of) a supply chain to become lean. These factors should be investigated before embarking on an effort to become lean.

Size specific conditions

Most research on lean thinking focuses on large organizations. As indicated before, due to lean thinking organizations are able to be more responsive to customer demand while requiring less equipment capacity and employ a more stable number of employees (Sugimori et al., 1977). Both elements, less equipment capacity and more stable number of workers are relevant for SMEs. SMEs generally do not have the financial capital available to acquire high equipment capacity. Also, since SMEs often are family owned and have an (almost) family-like relation with their employees, they generally aim to have a stable number of workers. Not having to hire temporary workers or having to fire people when sales are down is also less costly. This supports the assumption that implementing lean thinking is appealing for SMEs.

However, research about degrees of implementation of lean methods shows a negative correlation between organization size and degree of implementation (Shah & Ward, 2003; White, Pearson, & Wilson, 1999). It seems that smaller organizations are less able to implement a wide variety of lean methods, either due to a lack of organizational capability or financial resources, or due to an inapplicability of lean for smaller organizations. Rose, Deros, and Rahman (2009) suggest that a lack of financial resources impedes lean implementation in SMEs and that SMEs should therefore focus on the methods which require little investment, such as 5S. Research of Shah and Ward (2003) shows that when considering the combined effect of implementing different methods, large organizations are at a disadvantage. Smaller organizations seem to gain more operational improvement as an effect of implementing lean methods. Hence, even though smaller organizations implement less lean methods, they seem to be able to achieve superior performance improvements by the combined effects of the methods they implement.

Little literature on specific cases of implementation of lean methods in SMEs can be found. The limited available literature reports positive results of lean implementation (Grewal, 2008; Kumar et al., 2006; Vinodh, Arvind, & Somanaathan, 2010). Some other authors have written lean ‘instruction manuals’ for small organizations (Conner, 2009) and startups (Ries, 2011). Further research, less focused on lean thinking, showed that SMEs can generate value by decreasing their inventory levels (García-Teruel & Martínez-Solano, 2007). Lower inventory levels is a common effect of lean thinking.

Based on the available literature it is difficult to state conclusively that lean is or is not particularly applicable for SMEs. Some research shows that smaller companies struggle more to implement lean methods. Other research reveals positive effects of lean in SMEs. This thesis aims to contribute to investigating if SMEs should pursue the implementation of lean thinking.

The following section will describe the problems faced in implementing lean, the factors critical to successful implementation and various implementation methods. Finally, by evaluating the implementation methods by the critical success factors the most appropriate method will be identified.

2.3. LEAN IMPLEMENTATION

Implementing lean and achieving relevant results has proven to be difficult. Baker (2002), Corboy and O'Corrbui (1999), and Sohal and Egglestone (1994) state that only ten percent of companies is successful when attempting to implement lean. One of the major barriers to successful implementation is the misapplication of tools. The misapplications can be of three kinds; using the wrong tool for a certain problem, using one tool to solve all problems and using all tools on every problem. Misapplying lean manufacturing tools may waste additional time and money and it may decrease the confidence employees have in implementing lean manufacturing (Pavnaskar et al., 2003).

The problems with the correct usage of tools shows that there is a need for guidance. For a lean implementation method to be useful it should at least offer this guidance. Below, critical success factors of improvement programs in general and for lean efforts specifically are linked to further implementation methods characteristics.

Implementation method characteristics

Indicate what tools to use

A problem of lean implementations is that companies start with using one tool or a group of tools and push them through the entire organization. They then find out that their process does not improve (Sheridan, 2000). It should be taken into account that elements of lean tools and practices have systemic relationships and therefore cannot be implemented in isolation (Hayes, Wheelwright, & Clark, 1988). Research shows that the effect of combined implementation of tools explain about 23 percent of the increase in operational performance (Shah & Ward, 2007). The critical number of implemented lean tools seems to be four. Companies implementing at least four lean tools show significantly higher productivity growth than their counterparts not implementing lean or not implementing enough lean tools (Engineering Employer's Federation, 2001). Merely starting with one of the popular lean tools is not sufficient. The implementation method should therefore take a holistic view of the process and indicate possibilities to implement various lean tools.

Show benefits beforehand

Lean implementation efforts are tedious and require perseverance. On average, SMEs need three to five years to implement lean to a reasonable extent and to be able to maintain the effort on a long term basis (Emiliani, Stec, Grasso, & Stodder, 2003). Similar findings are reported for larger organizations (Portioli Staudacher & Tantardini, 2010). Therefore, an essential factor in reaping benefits from a lean implementation is strong upper management involvement (Scherrer-Rathje, Boyle, & Deflorin, 2009; Worley & Doolen, 2006). Furthermore, top management involvement is key in overcoming inevitable resistance to change, through leading by example (Kessler, 1999).

In order to convince top management, the initiative should have a clear link to the mission and goals of the company and it should be clear how the initiative will lead to a structural increase in profit (Sim & Rogers, 2008). Preferably, the benefits of implementing lean methods are quantified before the actual implementation takes place. This allows management to understand the increase in performance when changing from the current system to a new, unknown system (Detty & Yingling, 2000). This is especially relevant for SMEs, since they possibly have less opportunity to set up pilot programs, for instance in one department or on one production line. Such a pilot would possibly span the entire company, as SMEs sometimes only have one production line or department. The last implementation characteristic is that the necessary changes to the process should be visualized to allow management to create a mental picture of the future process (Achanga, Shehab, Roy, & Nelder, 2006).

Enhance cultural change

Critical for successful lean implementation is cultural change and acceptance of the new mindset throughout the organization (Bhasin & Burcher, 2006). This change, and the acceptance of new tools, can be impeded by mistrust of employees. Kumar et al. (2006) experienced this in one of their case studies. Support of the production employees was achieved by convincing them their jobs would not be endangered by the lean implementation. Instead, they would be rewarded for improved performance. Karlsson and Åhlström (1995) propose a reward scheme aligning individual performance rewards with organizational goals. This element is more a managerial choice than a characteristic of an implementation method. It is included to emphasize the importance of cultural change.

Summarizing, the implementation method indicates what lean tools to use where and visualizes the necessary changes, it quantifies the (financial) effects of the changes up front and possibly it supports the cultural change process.

Implementation methods

Various authors have proposed methods to implement lean thinking in organizations. The most important methods will described and evaluated according to the characteristics as described before.

Åhlström (1998) suggests that during the first phase of the project most focus should be on achieving zero defects and delayering the organization. Later, the focus should shift to continuous improvement. During the entire project, management should put efforts in eliminating waste, creating multifunctional teams, implementing pull scheduling, giving a lot of responsibility to team leaders, and instituting a vertical information system in which relevant information is shared amongst all employees. However, he does not offer a hands on approach on what tools to implement where and in what order. Neither does he propose a method to quantify the achievable benefits nor does his method include a clear visualization of the required changes or the potential benefits.

In a different article, Karlsson and Åhlström (1996) propose that companies should start lean efforts by implementing ‘quality circles’. These are small groups of employees who meet on a regular basis to discuss improvement possibilities. This increases the involvement of the employees in the lean implementation and subsequently the number of suggestions for improvement. Furthermore, for certain lean elements, such as ‘elimination of waste’, ‘continuous improvement’, or ‘multifunctional teams’, they identify key determinants and levels of implementation. This method gives some indication of how to increase the level of ‘leanness’, but lacks guidance in what tools to use or how to quantify the effect of the changes.

A third method to implement lean is simulation, as proposed by Detty and Yingling (2000). By modeling the current and future process and simulating them digitally, this method gives a precise prediction of the performance increase. The advantage of simulation is that results are detailed and offer strong insights in future performance. However, simulation is expensive and therefore possibly not practical for SMEs. Also, such simulation still requires an analysis of the system to choose what lean tools are needed. Simulation only provides validation of the expected results.

Another method for companies to implement lean is Value Stream Mapping (Rother & Shook, 2003). The first step of VSM is to identify the current state of a selected process or product family. This results in a visual representation of all information and material flows and gives an insight of the ratio between value added and non-value added time. This current situation is then analyzed based on seven questions regarding the need and possibility of product flow in the process. This analysis results in a future-state map. The VSM process then analyzes what improvements should be made in the current process to enable the implementation of the future state. The final step includes planning and implementing the future state process. As described, VSM gives an indication of what tool to use where. The future state map is a visualization of the necessary changes and their effects. However, VSM lacks an evident connection to cultural change.

The final proposed model prescribes that a lean implementation should start by creating awareness throughout the company (Productivity Press, 2002). Then a 5S effort is performed to increase tidiness. This is followed by the implementation of a series of lean methods. The book gives a clear instruction of the steps to follow in the process of becoming lean. The method discusses how to achieve essential cultural change, albeit rather superficially. However, the method lacks a sound evaluation of the potential benefits. In addition, the description of where to implement exactly what tool is too limited to be of enough guidance.

From the description and evaluation of the five implementation methods the following conclusions can be drawn. The first two methods and the fifth method offer no upfront indication of what can be achieved by the lean effort. This is essential to get enough upper management commitment. The first three methods do not sufficiently prescribe how to use what tool and where in the organization. As such, these methods will not prevent companies from making the traditional implementation mistakes. The first, third, and fourth methods lack emphasis on cultural change, and the final method only mentions this element superficially.

Combining these observations leads to the conclusion than none of the proposed methods meets all requirements of an appropriate implementation method. However, the most appropriate method seems to be Value Stream Mapping. This method gives a clear indication of what tools to implement where in the company. With the method it is possible to quantify the potential gains and to visualize where waste currently occurs. It is hypothesized that by the clear visualization of the current process and its waste it is possible to instigate the necessary cultural change.

The conclusion that VSM is the most appropriate method to start with lean is in line with what various authors have claimed (Pavnaskar et al., 2003; Singh & Sharma, 2009; Vinodh et al., 2010). In large companies this method has proven to deliver relevant results (Lasa et al., 2009). This thesis aims to contribute to the investigation if VSM can deliver similar results in SMEs.

3. METHODOLOGY

This section will describe the research strategy and methodology used to answer sub research question C. First, the considerations which are taken into account when choosing the research strategy will be discussed. Then, the research strategy will be developed further. Next, the VSM technique will be discussed in more detail. Finally, the data gathering methodologies will be described.

3.1. RESEARCH STRATEGY

The research strategy should have a number of characteristics. First, the research should take place in the context natural to the process, to be able to identify relevant contextual factors. Then, potential necessary data should be present and accessible to the author and the fact that the research is taking place should have a minimal effect on respective process. Finally, the research should be able to be performed during the time frame available for this research.

These three characteristics are met by case study research. Gerring (2004) defines a case study as "(…) *an intensive study of a single unit for the purpose of understanding a larger class of (similar) units*. A unit connotes a spatially bounded phenomenon (…)" (p. 342) This strategy distinguishes itself by examining a phenomenon in its real life context (Yin, 1981) and therefore allows the researcher to understand what really happens in an organization and how processes lead to results (Gillham, 2000). Case studies can combine different data collection methods, such as interviews, surveys, and observations. The gathered data can be qualitative, quantitative, or both (Eisenhardt, 1989). The possibility presented by case study research to understand a phenomenon in depth and to combine various types of data for different questions makes this strategy well suited for the combination of research questions researched in this thesis.

The case study research strategy was heavily criticized as a strategy to develop relevant new knowledge (Ellram, 1996; Miles, 1979). Critique was expressed in unambiguous terms:

> Such studies have such a total absence of control as to be of almost no scientific value. (…) Any appearance of absolute knowledge, or intrinsic knowledge about singular isolated objects, is found to be illusory upon analysis. (…) It seems well-nigh unethical at the present time to allow, as theses or dissertations in education, case studies of this nature (i.e., involving a single group observed at one time only). (Campbell, Stanley, & Gage, 1963, pp. 6-7)

Most critique revolved around two main assumptions about case studies (Ellram, 1996). First, case studies were thought of to only include qualitative data, which was expected to deliver less valuable insights. Second, case studies were seen as single data points, which limits the degree to which the conclusions of a case study research can be generalized. Work of various authors has shown that these assumptions are flawed and that relevant results can be obtained and valid theories can be developed through case study research (Eisenhardt, 1989; Ellram, 1996; Flyvbjerg, 2006; Gerring, 2004; Yin, 1981).

A variation of case study research is case-survey research. For this strategy, data of various cases is gathered and analyzed to draw conclusions about a certain phenomenon. As a result, this strategy could yield more statistically valid results. Two prerequisites for this strategy are that isolated factors are significantly interesting and that the number of case studies is large enough to be able to draw solid statistical conclusions (Yin, 1981). This research aims to capture various contextual elements of the lean implementation process and thus no single interesting factor can be isolated. Furthermore, the number of known cases of Dutch SMEs implementing lean is limited. This leads to the conclusion that the two prerequisites are not met and the case-survey strategy is therefore not a viable option for this research. This study will therefore focus on a single case.

The following section will describe the selection process of the case company.

Case selection

As described, lean manufacturing was primarily developed in the automotive industry. To be able to focus on the implementation method in SMEs, this research aims to research a case company which shares characteristics with this industry. This allows the use of the extensive literature about lean in such environments, without having to adapt the lean methodology to a significantly different field of use. According to Sugimori et al. (1977) the companies in the automotive industry have to deal with a few distinguishing problems: Assembly of complex products consisting of thousands of parts, in high volume but with a large variation in product range, and high fluctuations in demand per product variation. Also, they have to deal with relatively frequent product changes or renewal. Such companies can generally be categorized as discontinuous flow line manufacturing systems, where VSM was developed and where most results have been achieved with lean methods (Lasa et al., 2009). If the case company is categorized as such, it is more likely that lean manufacturing methods are applicable, which is of course vital to this research.

Furthermore, lean manufacturing was initially focused on increasing productivity and decreasing lead times. It is therefore preferred that the case company also predominantly has issues of these types. Finally, for considerations of generalization and relevance of the conclusions of the research it is preferred if the case company works in an industry which is relevant to the Dutch economy.

To find a suitable case company first an informal analysis of common production activities in the Dutch economy was made. Prominent examples are machine production and metal processing. Through branch organizations and websites, and through the personal network of the author, various companies from these sectors were approached. Meetings with different companies resulted in a number of possible case studies. The company used as a case for this thesis was chosen, because they had lead time and efficiency issues, they were committed to improving their operations, and because they have a production facility in the Netherlands. Other companies were oblivious to their problems or had all production facilities abroad, which could both hinder the research.

Case company description

Wheels Inc.[1] ('the company') produces machines for the bicycle production industry around the world. They have a production facility in the Netherlands, with which they cater to the higher-end product range, and a wholly owned facility in China, where they produce a more basic product range. As such, both facilities deliver products globally, albeit most high end, more automated machines are delivered to customers in Western countries, where labor costs are higher. At their production facilities, they assemble the machines from parts delivered to them by various suppliers.

The company is a family owned business, founded in 1971 and currently run by two grandsons of the founder. The Dutch facility has twenty-eight employees, consisting of: seven production workers, two warehouse employees, two procurement employees, a production planner, five installation employees, a sales team of three, five people involved in product development (software and hardware) and an administrative staff of three. The production employees are multi-skilled and most of them are able to assemble machines entirely or at least to a considerable extent. Some of the production employees also perform basic engineering tasks to improve product designs and technical drawings. The turnover rate of employees is very low. It is no exception to meet people who have worked at Wheels Inc. for more than twenty-five years.

The machines of the company perform different, specified tasks in the production process of bicycle wheels. These tasks are performed by hydraulically and electrically driven systems. These hydraulic and electric elements in the machines add to the complexity. The production volume is low and machines are customized to customer order to some extent. The

[1] The name and exact product of the case company cannot be disclosed due to confidentiality agreements.

complexity combined with low volume prevents the company from automating their production process. Therefore, labor costs constitute of a significant part of production cost.

In light of growing global competition, the management of the company aims to improve production performance. They have noticed that due dates are often surpassed while customers demand even shorter delivery times. Furthermore, the demand for machines built in the Netherlands is expected to increase. To meet this demand with the same personnel, productivity should increase. The management aims to maintain their production facility in the Netherlands, to keep a close link between production and product development. Their product development department is situated in the Netherlands as they find it easier to find qualified personnel there and due to issues with data and knowledge security in case of development in China. To be able to keep production in the Netherlands it essential to increase efficiency, to lower production cost, and to decrease production and delivery time.

To improve production performance, the management has started a facility wide improvement effort, to which this research contributes. This research focuses on the production process improvement.

Applicability of Lean

To understand if Wheels Inc. is an appropriate case for this thesis, it will be compared to the various characteristics of potentially lean companies as described before. First, the case company should fall within the set delimitations. Wheels Inc. can indeed be classified as a discontinuous flow line manufacturer and the company has productivity and lead time issues. Furthermore, as the company has less than 250 employees it is regarded as an SME. It therefore falls within the scope of this study.

The case company shares a number of characteristics with the automotive industry. Complex products, consisting of many parts are assembled at the facility of Wheels Inc.. The volume and level of product variation at Wheels Inc. are lower than in the automotive industry. On the other hand, Wheels Inc. also has to deal with the problem of fluctuations in demand per product variation. This overlap in characteristics allows for the expectation that lean methods are applicable to this company.

Finally, Wheels Inc. should pertain to a supply chain which can be classified as an efficient supply chain in the uncertainty framework. The demand for each product variation fluctuates to some extent, but the total demand is rather stable. Innovations occur frequently, but they are generally improvements to current technology rather than technological breakthroughs. The margin on the products of Wheels Inc. are high, but the product life cycle can be multiple decades. The demand uncertainty for the company is therefore considered to be medium.

On the supply axis of the framework the following observations can be made. Most parts are fairly simple and the processes to manufacture them are mature. Also, all but one specific part can be produced by a wide base of suppliers. Breakdowns in this supply chain are limited and suppliers are generally dependable. Supply uncertainty can therefore regarded to be low. The combined uncertainties in supply and demand lead to the conclusion that Wheels Inc. is a member of an efficient supply chain. Some demand uncertainty reduction strategies might be useful to decrease demand uncertainty even further.

Taking into account the various characteristics, Wheels Inc. can be considered to be an appropriate candidate for this research.

3.2. VALUE STREAM MAPPING

This section will describe Value Stream Mapping in more detail. For an extensive explanation and examples the reader is referred to the book “Learning to See”, by Rother and Shook (2003). Value Stream Mapping, known at Toyota as “Material and Information Flow Mapping”, is a method which helps practitioners to identify systemic sources of waste in a process and subsequently how to eliminate these source on a structural basis. A key characteristic of the method is that it looks at a process as a whole, rather than at the level of sub-processes (Jones & Womack, 2002; Pavnaskar et al., 2003; Rother & Shook, 2003). The method allows for process wide improvement, rather than local optimizations which often negatively affect other areas on the process. Emiliani and Stec (2004) show the wide applicability of VSM by using VSM for determining the beliefs, behaviors and competencies possessed by business leaders.

Waste and Value Streams

VSM revolves around two main concepts, “Waste” and “Value Streams”. Waste is “(…) anything other than the minimum amount of equipment, materials, parts, and workers (working time) which are absolutely essential to production are merely surplus that only raises the cost” (Sugimori et al., 1977, p. 554). According to TPS, there are the following seven wastes (Ohno, 1988), with possible examples of each waste:

- Waiting: A processed part is waiting in a box to be moved to the next step in the process, because not all the parts from the batch of this part have been processed at this step.
- Transport: A part is processed in one step, transported to the warehouse, put away and transported back to the production floor when the part is processed at the next step.

- Inappropriate processing: Cutting a part with a tolerance of 0,1 mm, while the customer only demands a precision of 0,5 mm.
- Overproduction: Producing more than demanded by the customer. This leads to excess inventory and possibly to obsolescence of products.
- Unnecessary inventory: Holding months of inventory of parts which are rarely used and available from a supplier on a short term basis without a cost premium.
- Motion: Tools or parts which are located far away from the place where they are used in the process.
- Defects: A mistake made in the beginning of the process is not detected until the product reaches a quality inspection at the end of the process.

Mastroianni and Abdelhamid (2003) added a eighth waste to this list: “Not utilizing human resources”. This is the common phenomenon that ideas for improvement from (production) employees are not gathered or not implemented.

As wasteful activities are Non-Value-Added (NVA) activities, there are also Value-Added activities (VA). These are the activities the customer is willing to pay and wait for. Finally, there are activities which are wasteful, but (currently) necessary to the process. This type of activities is classified as Necessary-Non-Value-Added activities (NNVA) (Monden, 1998). An example of an NNVA activity is when parts are transported to a different production hall, because in that area toxics are used and special safety measures have to be in place to ensure the well being of the employees. The transportation is wasteful, but essential to the production of the product.

The differentiation between VA, NVA, and NNVA activities leads to the second concept of VSM; the Value Stream. A Value Stream is “(...) all the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product (...)” (Rother & Shook, 2003, p. 14). Purely speaking this is the combination of all the steps from the production of raw materials to the delivery of the product to the final customer. To delimit the scope of the Value Stream, practitioners generally focus on the “door-to-door” production process inside a plant. This is practically more attainable and allows to focus on the process you can influence, namely the process inside your own factory.

Value Stream Mapping process

The Value Stream Mapping process consists of different steps. First, one product family, based on similar processing steps and required equipment, is chosen to be the focus of the improvement effort. This reduces the complexity of the studied process. The product family should be described and delimited clearly to avoid confusion in the following steps.

Current State

After choosing the product family the current state of the value stream is described in the typical VSM fashion. First, the information about customer demand is gathered. Essential information is the amount of products produced and the time frame in which this takes place, because this leads to the so-called “takt time”. The takt time is the average rate at which a product is demanded, spread over a certain production period. For example, if the average daily demand for product X is 450 pieces and the daily production time is 7,5 hours, or 450 minutes, the takt time is 1 minute. To fulfill demand, the process should be able to deliver a product every minute on average. It should be noted that the length of the takt time is unrelated to the amount of work content which is needed to produce one item. All gathered data is represented in one overview, to visualize the entire process and all its relevant aspects.

Then, all process steps the product family passes are defined. Examples of process steps are cutting, welding, or assembling. Per process step, some process characteristics are measured. Generally, these characteristics are data such as cycle time (the time it takes for one product to be processed at that step), change over time (the time to switch from the production of one type of product to the next), the available working time per day or per shift, the amount of workers simultaneously working at that process step, defect rates, and uptime information (percentage of working time in which the machinery is working properly). Information is also gathered about the delivery frequency to customers and from suppliers. To fully understand the process and to improve data quality it is advisable to collect these data first hand. Material movements between processes are visualized with different types of arrows, depending on the type of material management and handling between the two steps.

After describing the process steps, inventory levels between each step and at the beginning and end of the entire process are measured. Generally the inventory levels are expressed in volume and inventory time in days, hours or minutes. For example, there are 3600 pieces waiting in front of process step Y which takes half a minute per product and is demanded at an equal rate. With a working day of 450 minutes, it will then take 4 days to process the stock in front of process step Y. For reasons of simplicity down time and setup time are generally not taken into account. Practitioners argue that inventory levels only need to be measured once to give a general indication of how much time products spend waiting. They reason that even though inventory levels at each separate step can vary, normally the total level of inventory is more or less constant. Also, waiting time often represents such a significant fraction of the time it takes a product to flow through the entire process, that even if this fraction varies it still shows that products spend too much time waiting.

At the bottom of the process visualization a timeline is drawn. This timeline shows the total time a product takes to flow through the process, differentiating between value added time and non value added time. This timeline can give striking insights, for example: “It takes us four weeks to perform ten minutes of value added time.” The percentage of value added time respective to the total time can strengthen this argument.

Finally, all information flows are depicted. Essential information flows are the incoming order process, the procurement procedure and the production planning within the focus process. This visualizes possible inefficiencies in how necessary information flows between different departments and other stakeholders.

Now, the entire process and the relevant information and material flows are visualized in one picture. Also, there is some indication of the state of the process. The following step is to devise the future state of the process.

<u>Future State</u>

To come up with a future process which is lean and where root causes of waste are eliminated as much as possible Rother and Shook (2003) present seven guidelines for lean value streams and eight guiding questions to analyze the parameters of the process. The seven guidelines are as follows:

1. *Produce to your takt time*: produce at the rate customers demand your products.
2. *Continuous flow*: where possible, let products flow one piece at a time, instead of in batches.
3. *Supermarkets if continuous flow is not possible*: a ‘supermarket’ is a lean method to link a process step to an upstream step which still needs to be run in batches. When enough items have been taken from this supermarket, a signal is sent upstream to start production of one batch. In this way, total work in progress is limited and production is closely linked to actual customer demand.
4. *Schedule production at one step only*: as all the process steps are closely linked, either through supermarkets or through continuous flows, it is only needed to schedule production at one specific step. This is called the ‘pacemaker process’.
5. *Level the production mix*: if multiple types of products are produced in the same flow, it is essential to mix the production of the types as much as possible. For example, if products A and B are produced in one line, it can be tempting to produce a batch of product A during one week and a batch of product B in the next to decrease the number of change overs. However, this leads to higher levels of work in progress and final product inventories. Furthermore, it creates an unleveled demand for items which are used as input for the process. This, in turn, creates a ‘bullwhip effect’ of

increasing fluctuation in demand throughout the entire supply chain (Lee, Padmanabhan, & Whang, 1997).

6. *Level production volume*: release fixed amounts of work onto the production department. This allows the department to understand frequently if they are on schedule with their work and whether they should intervene.
7. *Shorten change over time:* focusing on shortening change over time allows to decrease batch size and thereby improves stability and enables a leveled production.

Linked to the seven guidelines there are eight questions which offer guidance to develop the future state of the process:

1. What is the takt time?
2. Will you build to a finished goods supermarket or directly to shipping?
3. Where can you use continuous flow processing?
4. Where will you need to use supermarket pull systems?
5. At what point will you schedule production? What is the pacemaker process?
6. How will you level the production mix at the pacemaker process?
7. What increment of work will you release to the pacemaker process?
8. What improvements are necessary to enable the implementation of the future state?

By answering these questions the future state becomes apparent. This future state is visualized in similar fashion as the current state. The percentage Value Added Time should have increased significantly. Finally, necessary improvements to reach this future state are depicted in the same overview.

The last element of the Value Stream Map analysis is planning the implementation towards the desired future state. To do so, the future state process is split in different segments, or loops. Then, the order in which the segments are implemented is defined and per segment a plan is made, including steps to take, responsibilities and goals.

There is no recipe for a lean implementation, but there are some guidelines about with what segment to start. It is advisable to start with a part of the process which is well-understood by the people involved in that area and where the odds of success are favorable. Furthermore, it is preferred to start in an area with large potential gains. It should be noted however, that this last criteria can be conflicting with the first two and this should be carefully dealt with.

Addition for high work content, low volume processes

The nature of the work at the case company complicates the data gathering process in three main ways. First, the demand for each type of machine is low and can vary significantly through and over the years. Second, the work content to make one machine is high; it takes a couple of weeks to build one machine and this work is done by a small group of production employees. Third, the different production steps across machines are similar, but the time it takes per step differs substantially. Combined this means that gathering data encompasses the entire production of one machine, or a small batch of them, since it is not possible to gather data from the production of other types of machines. This issue can be generalized to cases with high work content, low volume environments, such as specialist machine production.

3.3. DATA GATHERING

To gather the required data, one production employee will be observed during the production of a batch of three similar machines. This employee is able to perform all the tasks necessary to finish this type of machine. Focusing on one employee enables the observer to take detailed and accurate notes about the process. To support the observation process, an adapted version of the Process Activity Mapping tool was used (Hines & Rich, 1997), to be found in Appendix A. This tool allows an observer of any process to take notes about key information in a structured way. Each step in the process is written down separately, together with relevant data such as the time it takes to perform that step, the amount of people involved and the distance moved during that step. Furthermore, each step is categorized to differentiate between Value Added, Non Value Added and Necessary Non Value Added time. The categories, adapted to fit the work of the case company, are:

- *Process*: All the activities which add value in the eyes of the customer to the machine are included in this category.
- *Move*: Searching for and getting parts or tools. For this category, also the distance travelled is recorded.
- *Install*: As the machines need to be built with precision to work, it is necessary to position parts correctly respective to each other. These activities are necessary for the completion of the machine, but do not add value.
- *Inspect*: The production work in this facility consists mainly of assembly tasks. This category includes all the work done to ensure incoming parts are fit for use. This consists of quality checks as well as corrective activities.
- *Wait*: Waiting, for example for tools or parts to be available, is recorded into this category. Consulting with fellow workers or management is also included.

All data will be recorded in two ways, from the viewpoint of the employee and of the machine. In case of the machine, this means that the described action is performed on the machine. “Wait” then means that no action is performed on the machine during that period.

The categories do not include all seven wastes. As all machines are produced to order, there is no overproduction. Furthermore, it is out of the scope of this research to investigate if the amount of processing and the precision applied are as the customer requires.

During the observation period, improvement suggestions are identified and quantified in terms of saved time and walking distance. This offers additional improvement possibilities for the VSM analysis.

The mere presence of an observer might influence the productivity of the employee under observation, which can endanger the validity of the gathered data (Gillham, 2000). The effect of the observer is aimed to be minimized to have the highest validity of the data. First, an employee will be selected who is able to deal with the oddity of being observed while working. The selected employee is made to understand that he will not be judged on his performance as measured for this research. The employee will also get full insight in the data gathered and in the conclusions drawn from that data.

The following section will elaborate on the VSM analysis of the case company.

4. Value Stream Mapping applied

This section will illustrate the results of the steps described in the methodology section. First, one product family is selected. Then, the current state is described and data is gathered to understand each process step in more detail. Subsequently, a future state is proposed accompanied by a description of the most important improvements suggested, and an implementation plan is offered.

4.1. Product Family

Wheels Inc. has a variety of products, differing significantly in function. However, the production process across the different varieties is rather similar. Knowledge acquired about a certain product type can therefore be generalized to most other products. As a result, the choice of a specific product family was less critical in this case.

As the chosen data gathering methodology was direct observation, it was essential that the chosen product was manufactured during the timeframe of the research. This practical requirement limited the choice of product families to three. Product A was a highly specialized machine, which is sold only every couple of years. Product B was a machine of which most work is done in the Chinese facility and the demand for this product varies substantially over the years. Product C is a machine with high demand and which offers the company a competitive edge. A batch of three products C was planned to be produced during the research period, which increased the possibility to cross check the gathered data. Furthermore, after the research period more products C are planned to be manufactured. This allows for direct implementation of the proposed improvements to the process. It was therefore decided that product C was most valuable as the focus product family.

Even though product C was chosen as the focus product family, some of the analyses were performed looking at the entire Dutch production facility of Wheels Inc. for a number reasons. First, the fluctuation in demand, even for product C, can be so significant that certain data can be valid this year, but of no use the next. Second, all products are manufactured using the same (human) resources in the facility. Furthermore, the demand for most products is so low, that certain data, such as takt times, do not relate adequately to how the company serves its customers. Finally, the recommendations from this thesis will be applied to the entire production facility and this should be taken in consideration while performing certain analyses.

It will be indicated clearly when analyses relate to the entire production facility.

4.2. CURRENT STATE

After the product family was selected, the current state of the process is described. First, takt time and other basic information about the process was gathered. Then, the process steps of production were described and data about each step was collected. Finally, information flows were analyzed.

General process information

The annual production period of the company is 200 days. Over the span of this period 68 machines are manufactured. This results in a takt time of 2,94 days. Subsequently, the production facility should have the capacity to produce one machine every 2,94 days. However, demand is not balanced evenly over the year. During the first and last three months of the year, a total of 46 machines are demanded. The takt time for this period is 2,17 days. The facility should be able to cope with the 'busy' period demand and with the expected rise in demand. For the remainder of the analysis a takt time of 2 days will therefore be used.

One working day constitutes of 8 working hours or 480 minutes. Breaks are not included in this period. Machines are shipped to the customer as soon as the machine, or total order consisting of a number of machines, is finished.

Process steps

The manufacturing process of product C consists of several discernible steps:

- *Subassemblies*: The machines consist of several subassemblies. These are manufactured before the final assembly of the machine starts.
- *Mechanic*: The first step of the final assembly is building the mechanic structure of the machine. Most of the subassemblies are added to the machine during this step.
- *Pneumatics*: Most of the functions in the machines are driven by pneumatics. The tubes and driving systems are connected.
- *Electronics*: All systems in the machine are controlled by electronics. During this step, the electronics panels are mounted in the machine and all electronic connections are made.
- *Programming*: The final step in the process is adding some client specific software settings to the machines. This step also includes adjusting the positions of measurement instruments in the machines.

Process data

The observation period was 11 working days[2], in which 3.954,5 minutes of employee working time was recorded with a total of 354 actions. Actions were only recorded if they were related to the production of the batch of products C. For instance, when the observed employee gave instructions to an intern, this was not included. This was decided to focus the gathered data on the actual production of product C.

The observations show the following time distribution[3] from the perspective of the production employee.

Category	Time (min)	Fraction (%)
Process	1.784,8	45,1%
Move	307,2	7,8%
Install	1.169,0	29,6%
Inspect	614,5	15,5%
Wait	79,0	2,0%
Total	**3.954,5**	**100,0%**

TABLE 1: TIME DISTRIBUTION OF EMPLOYEE

While recording the times of the different activities, the distance covered by the employee was also observed. In total the employee walked 2.359 meters.

During the observation period it was also observed what actions were performed on each of the three machines of the batch. In general, when the observed employee was working on one machine the other two machines were waiting. At some point during the observation period a second production employee started to perform tasks on one of the machines. Recording the actions of both employees would have endangered the validity of the observations. The activities of the second employee were therefore not included.

The time spent by the machines is depicted in the following table.

	Machine 1		Machine 2		Machine 3		Total	
Category	Time (min)	Fraction (%)	Time (min)	Fraction (%)	Time (min)	Fraction (%)	Time (min)	Fraction (%)
Process	75,5	7,1%	707,8	27,7%	621,5	23,9%	1.404,8	22,6%
Move	44,2	4,2%	173,5	6,8%	110,5	4,2%	328,2	5,3%
Install	406,0	38,3%	188,5	7,4%	91,5	3,5%	686,0	11,0%
Inspect	82,0	7,7%	308,5	12,1%	130,0	5,0%	520,5	8,4%
Wait	452,7	42,7%	1.177,0	46,1%	1.650,9	63,4%	3.280,6	52,7%
Total	**1.060,4**	**100,0%**	**2.555,4**	**100,0%**	**2.604,4**	**100,0%**	**6.220,1**	**100,0%**

TABLE 2: TIME DISTRIBUTION OF MACHINES

[2] The observation period spanned three working weeks. Due to practical issues, the observer could not be present at all time.
[3] Confidentiality was agreed upon with Wheels Inc.. Therefore, the raw data can only be distributed upon request and with explicit permission of Wheels Inc..

Discrepancies between times for different machines can have different causes. The fact that machine 1 seems to have spent less time in the process is a result of not recording the actions of the second employee. Other differences are a result of the practical issue that the observer was not always present. Some activities for certain machines were performed when the observer was absent. The most apparent example of this is the difference in Install time. The Program step, which mostly included Install time, was only observed at machine 1.

As these observations are a combination of fragments of the manufacturing process of product C, it was necessary to combine the fragments to one generic process. This was done by lining up all the steps, which together form the process as if only one machine is produced, with the respective recorded distances and times. If process steps were recorded more than once, the average time and distance were taken. When the observation period started, the subassemblies had already been assembled. Data about the subassembly step were therefore taken from the company's information system, which does not include a differentiation of the different activities. Performing all the tasks for the subassemblies takes 2.975 minutes and is usually scheduled to start two weeks before the production of the machine is planned to begin.

To gain more insight in how time is spent during each step of the process, the data is presented per process step. The subassembly step has been omitted, since it was not part of the observation period.

			Category				
Process step		**Total**	**Process**	**Move**	**Install**	**Inspect**	**Wait**
Mechanic	(min)	535,7	222,7	86,1	80,3	106,7	40,0
	(%)	100,0%	41,6%	16,1%	15,0%	19,9%	7,5%
Pneumatics	(min)	403,0	259,5	25,0	0,0	118,5	0,0
	(%)	100,0%	64,4%	6,2%	0,0%	29,4%	0,0%
Electronics	(min)	1.392,5	996,0	145,5	24,0	131,0	96,0
	(%)	100,0%	71,5%	10,4%	1,7%	9,4%	6,9%
Programming	(min)	1.410,0	360,0	2,0	833,0	195,0	20,0
	(%)	100,0%	25,5%	0,1%	59,1%	13,8%	1,4%
Total	**(min)**	**3.741,2**	**1.838,2**	**258,6**	**937,3**	**551,2**	**156,0**
	(%)	**100,0%**	**49,1%**	**6,9%**	**25,1%**	**14,7%**	**4,2%**

TABLE 3: GENERIC PROCESS TIMES, PER PROCESS STEP

The translation from the observation data to the generic process is prone to errors, thus verification of these data is required. However, triangulation of the data with data from the company was not possible, due to two main reasons. First, the company does not differentiate the time spent in different categories and some process steps are recorded collectively. Second, the data available at the company shows recordings of a period when the manufacturing process of product C differed significantly from the current process. The data were therefore verified by the employee and his managers. They acknowledged the data and that they could be used for the remainder of the analysis.

For the generic process, the distances covered per process step were calculated to be as follows:

Process Step	Distance (m)
Mechanic	708,5
Pneumatics	258,0
Electronics	1.080,0
Programming	40,0
Total	**2.086,5**

TABLE 4: GENERIC PROCESS, DISTANCE COVERED PER PROCESS STEP

There are three flows of material coming from suppliers. The first flow is from local suppliers delivering parts which need to be blackened, for cosmetic purposes. The lead time for such orders is around five weeks. These parts are sent to Wheels Inc. and when there are enough parts, they are sent to the company which blackens them. It takes around two weeks before the parts are returned to Wheels Inc.. Second, local suppliers deliver specialist parts which are needed in the subassembly step. Normally, these parts do not need further treatment and also have an order lead time of five weeks. Finally, the Chinese subsidiary supplies parts for the subassemblies as well as for the casing and structure of the machines. The subsidiary has a lead time of six weeks after which the parts are transported to the Netherlands. Once a month a container is filled and then transported by ship, taking seven additional weeks to reach the factory. Some, mostly valuable, light, and small parts are sent by air transport, by which they take five working days to arrive. The chosen means of transportation depends strongly of the physical characteristics of the part and the urgency with which it is required.

Inventory levels

There is no, or very little, inventory of finished machines. The vast majority of machines are produced to order and shipping is only delayed if other machines for the same customer are soon to be finished. Between the process steps, from Mechanic to Programming, there is a constant inventory level of two machines. For simplicity reasons, the process will be described as if only one employee works on the batch of machines. This is common practice in the facility.

The Subassembly step normally starts two weeks before the assembly of the machines. This means that on average there is one week's worth of inventory of subassemblies. However, due to supplier issues delays often occur, resulting in additional waiting time for the subassemblies. As this extra waiting time is highly unpredictable, it will not be taken into consideration for the further analysis. Adding an arbitrary waiting time would cause discussion, distracting from the main analysis.

Finally, there is inventory of parts before the Blackening process step. To decrease transportation cost, material is stocked until a certain volume has been reached. Only then the materials are sent to the company which blackens them. On average, the materials are piled up for two weeks. Usually, there is no inventory of blackened materials, because as these parts generally arrive late, they are immediately needed in the Subassembly phase.

Timeline

The following step in the VSM process is to add a timeline, which shows the flow of a single machine through the process. The timeline differentiates Value Added time and (Necessary) Non Value Added time (N)NVA. In high volume value streams the processing time, the time a part is actually in a machine or processed by an employee, is taken to be fully Value Added time. Non Value Added time mostly accumulates in inventory time and Necessary Non Value Added time in quality inspection at the end of the process.

In the case of Wheels Inc. a considerable portion of the (N)NVA time is found within the process steps. To clearly indicate this, the timeline for this case will differentiate Value Added time, Inventory time (IT), and (N)NVA time within the process. In this timeline Inventory time occurs after a process step, because this simplifies indicating that there is no Inventory time after the Programming step. Inventory time differs from Wait time, as Wait time occurs within the process step and Inventory time between two process steps.

To give an insight about total order lead time a second timeline is added. This timeline solely indicates the time it takes from the moment a customer places an order until this order leaves the factory. Various scenarios are reflected in this timeline. First, if there are no materials present at the factory at the moment an order is placed, the full delivery time of Chinese suppliers is needed to start production. However, based on predicted sales, sometimes bulky parts have been procured in advance. In this scenario, the smaller items are flown from China to the Netherlands and the start of the internal process is restricted by the lead time of blackened parts. These parts are normally not held in stock. Furthermore, the lead time of the Subassembly step can vary between two and six days, depending on the amount of employees allocated to this step. The effect of supplier issues on delivery time has not been included, because it cannot be prudently quantified.

Information Flows

The sales force of Wheels Inc. has close relationships with most customers and together they discuss the specific needs to which Wheels Inc. can cater. Machines are customized to a certain level to fulfill the customer wishes. As this analysis focuses on production, the intricate sales process has been left out of scope. The relevant information flow starts when a final sale is made and an order lead time is agreed upon. Normally this lead time is around three months plus transportation time from the factory to the client.

Together with the CEO the sales force aims to predict upcoming sales of machines. This is then discussed in a weekly meeting between the CEO, the sales department, the production manager and the procurement manager. Together they decide what machines will be scheduled for production. This is put in the Manufacturing Resources Planning (MRP) system which then serves as an input for the procurement manager who orders products with the suppliers. The production manager bases the production plan on the MRP output as well. He communicates a monthly and weekly production schedule to the production employees by a printed planning which is located centrally in the production hall. On a daily basis the production manager communicates changes in the planning, often caused by disruptions in the supply chain.

Sometimes it occurs that the production planning is influenced by the CEO or the customer service manager. They receive inputs from clients and try to accommodate to their demands.

Value Stream Map

All the information about the process is visualized in the following VSM diagram. To be able to relate to the quantities more easily, the times have been presented in weeks or hours.

From the VSM diagram it becomes clear that the minimal delivery time, if machine casings and structures are held in stock, is 14 weeks. As a consequence, the promised delivery time of 3 months, 13 weeks, is not attainable. In order to deliver as promised, parts from both local suppliers and the Chinese subsidiary have to be ordered based on forecasts. Currently the ordering rules are based on experience, intuition, and basic rules of thumb of different people within the company. It is highly favorable to decrease total delivery time to less than 13 weeks, to reduce the need to forecast demand.

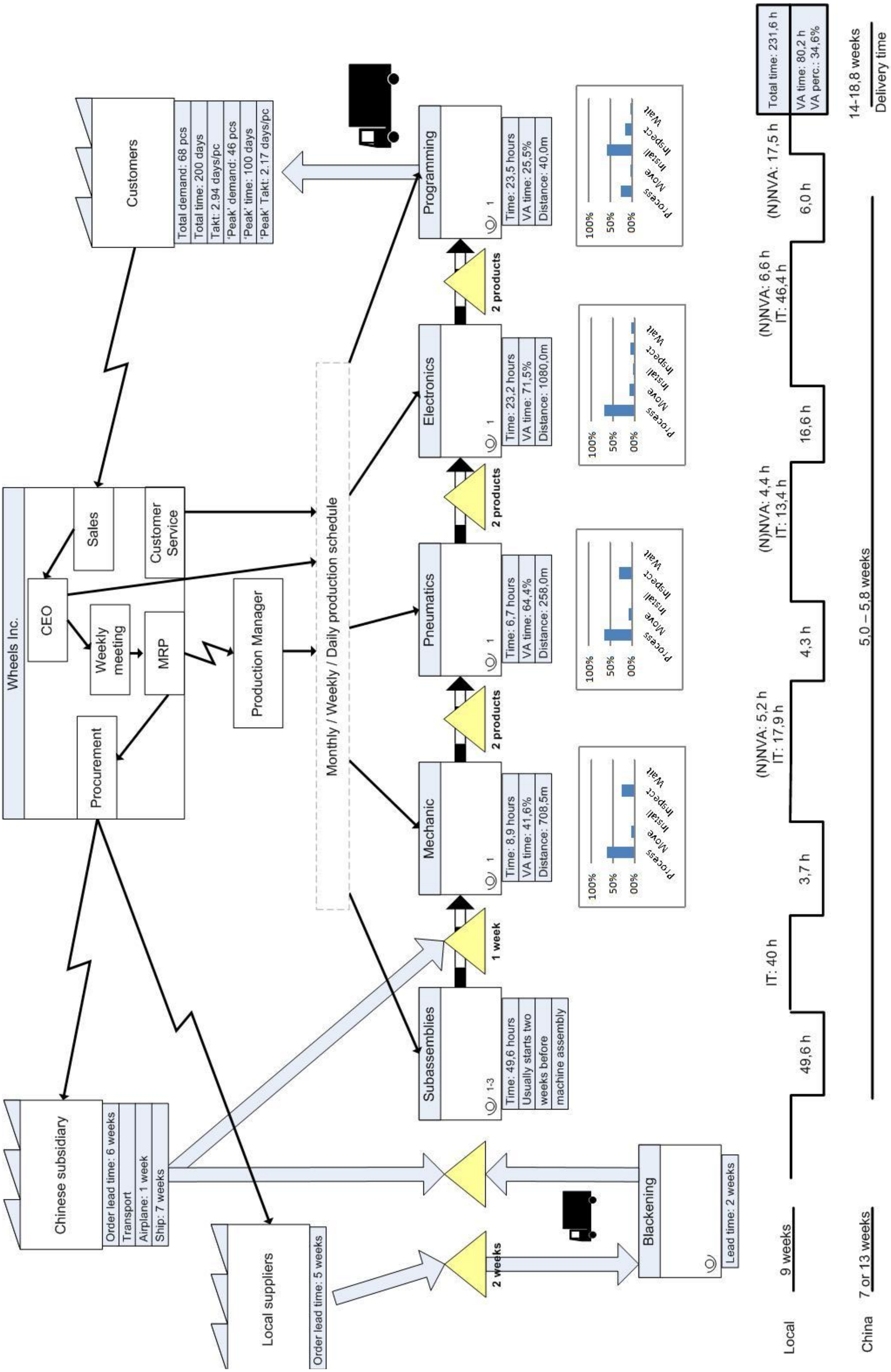

FIGURE 2: CURRENT STATE VSM

4.3. Future State

The result of the previous section is a detailed description of the current state of the process. The visualization of the process indicates that there is potential for improvement. This section will first discuss the eight guiding questions for the future state analysis together with the improvement suggestions for the process. Finally the future state map is presented. The implementation plan will be discussed in the following section.

Guiding questions

Each of the eight guiding questions will be discussed separately in this section.

<u>What is the takt time?</u>
As discussed in the Current State section, the company does not have a constant demand throughout the year. However, since the facility should be able to cope with 'peak' demand and demand is expected to rise, a takt time slightly higher than current 'peak' takt time is used for the future state map. As stated before, the used takt time is **two days per machine**.

<u>Finished goods supermarket or direct shipping?</u>
Most machines produced by Wheels Inc., especially in the Dutch facility, are built to specific customer orders and customized when needed. This means that there is no use for a finished goods supermarkets and therefore machines are **shipped directly** after manufacturing has finished.

<u>Where to use continuous flow?</u>
Continuous flow is possible downstream from the **Subassembly step**. From that step onwards, all production can be a one piece flow. The flow of materials from local suppliers, some of which have to be blackened, should also link closer to the production pace and order of the main process. This requires more frequent deliveries, especially to and from the blackening company.

<u>Where supermarkets?</u>
A supermarket system with **machine casings and structures** would greatly decrease delivery lead time. However, currently the variety of machine casings and structures prevents the company from doing so in a financially responsible manner. The amount of stock needed would be excessive. In order to make this a viable option, the company should increase their current effort to decrease the amount of varieties. This would in turn allow for an inventory of casings and structures to be held in the Dutch facility. Orders for new casings and structures would then placed with the Chinese subsidiary to refill the supermarket.

Pacemaker process?

The pacemaker process is where the schedule is imposed on the process. Generally it is the most upstream process of the continuous flow, which in this case is the Subassembly step. Conversations with the production manager and production employees revealed some practical issues with electing the Subassembly step as the pacemaker process. Primarily this concerned the fact that production capacity at the Subassembly step can be changed promptly, by assigning more or less human resources. This is often necessary, because most production employees also fulfill tasks aside production. Furthermore, they indicated that it was easier to understand a production pace of one machine every two days than a pace of a varying amount of subassemblies to be produced every two days. This amount varies, because the number of subassemblies per machine differs per type of machine and the production time per subassembly varies as well. It was therefore decided the **Mechanic step** will be the pacemaker process and the Subassembly step will be scheduled according to the available capacity.

How to level production mix?

As the analysis focuses on product C, there is no need to level the production mix. However, a wider variety of machines should be taken into consideration, because in the long term the entire production facility is aimed to be organized as the proposed future state map. Then, production mix should be leveled. Conveniently, this naturally happens by the nature of demand for the products of Wheels Inc.. Customers either require small amounts of similar machines or, and this happens more often, they need different machines in one order. By planning production in the **order in which machines are sold**, production is already leveled to a great extent.

What increment of work?

Generally the increment of work released at the pacemaker process is a multiple of the takt time. In the case of Wheels Inc. that is an increment of **two days of work**. It would be favorable to release smaller increments of work in order to have a more frequent feedback about progress. However, the nature of the work prevents that. An indication could be given per step what progress should have been made after a certain amount of hours to give intermittent feedback.

What improvements are needed?

To enable producing in a stable, one piece flow environment numerous improvements are necessary. This section will describe the key improvements relevant for the entire process. The following section elaborates on the improvements within the process steps and the subsequent possibility to rebalance the production process.

- *Produce to takt time*: To cope with future demand the facility should produce one machine every two days. This pace should be set for the entire production facility. This is commonly achieved by organizing production in a line configuration. The different process steps get specific workstations and the machines pass each workstation. Every two days, all machines are moved to the next workstation.
- *Schedule at specific steps*: As described, scheduling will be needed at two steps. It is key to only schedule at these two steps. The rest of the process products should flow through the process in a 'First In First Out' (FIFO) order. This makes the process predictable.
- *Supermarket of casings and structures*: In order to decrease delivery lead time substantially, it is necessary to have some inventory of parts in the facility. This is especially relevant for bulky products which need to come from China by boat. Further rationalization of machine design is needed to achieve this.
- *Milk run for blackened parts*: Currently, all parts which need to be blackened are delivered to Wheels Inc. and stocked there before they are sent to the blackening company. This process can be improved by a so-called 'milk run'. This milk run means that every week a courier drives to all local suppliers. There he or she collects the finished parts which are then brought to the blackening company, if needed, or to Wheels Inc. at the final stop. At the penultimate stop, the blackening company, finished parts are also collected to be brought to Wheels Inc.. This decreases delivery lead time of all parts and inventory levels at Wheels Inc.. The procurement manager at Wheels Inc. also believed that by this milk run, the delivery time of the blackening company and other suppliers could be cut by a week, because they also pile up parts before transporting them to Wheels Inc..
- *Stable delivery of parts*: As the company will be producing at a fixed pace, the delivery of parts too should be at a stable, dependable pace. Parts will also need to be delivered in the correct order. If parts are delivered at a steady pace and in the right order, they can be delivered just in time for when they are needed. This decreases handling time of those parts within the facility of Wheels Inc..

Process step improvements

During the observation period, various possibilities to increase performance within the process steps were identified. To check the viability of the suggestions, they were discussed with different employees of the company. The main categories of improvements are:

- *Quality of incoming material*: On a regular basis throughout the entire process incoming materials need adjusting to be usable. This is either a result of poor supplier performance or of suppliers provided with faulty order information.
- *Correct electronic schemes*: Mistakes in electronic schemes occur sporadically, but when they happen they cause major disruptions in the production process. It is hard to recognize that a problem is caused by an error in the electronic schemes rather than by a physical inaccuracy in the machine. Then, when it becomes apparent an error in the electronic schemes is the cause, it takes time to identify the exact mistake.
- *Clear work instructions*: Since demand for specific types of machines is low, employees encounter specific machine types irregularly. This means it takes time to remember what steps to take. Some employees keep personal work instructions, but these are not commonly shared and are often not complete. A common work instruction would decrease the time employees spend on thinking what to do next and on updating their personal work instructions.
- *Place parts closer to workstation*: Employees need a considerable amount of time to locate and get the necessary parts. Parts are placed in a chaotic way in the production area without indications of which parts are where. Parts intended for a specific machine should be placed together on one or two carts which have clearly indicated for what orders those parts are needed. These carts should then be placed close to the workstation where they are needed. Furthermore, parts should only be released to the production area when the production of the respective machine requires them.
- *Workplace design*: Currently workstations are not designated for a specific function within the production process. As a result, employees all have a fully equipped tool box, making it hard to find the correct tool quickly. Specific tool ‘plates’ should be designed per workstation. Furthermore, each workstation should have waste bins located closely, to reduce cleaning time.
- *Other*: Some minor improvements, such as adding order information to each machine and removing certain parts from the bill of materials, make up the final category.

To understand the influence of the improvements on the process time, an analysis per individual step was made to quantify the expected decrease in time needed to perform that step. The aggregate of this analysis can be found in the following table:

Current process time:	3.741,2	minutes
Current distance travelled:	2.086,5	meters

	Time		Distance	
Improvement	**Decrease (min)**	**Decrease (%)**	**Decrease (m)**	**Decrease (%)**
Quality incoming material	569,5	15,2%	149	7,1%
Correct electronic schemes	295,0	7,9%	0	0,0%
Clear workinstructions	135,0	3,6%	52	2,5%
Place parts closer	83,5	2,2%	1.002	48,0%
Workplace design	25,8	0,7%	292	14,0%
Other	24,0	0,6%	10	0,5%
Total	**1.132,7**	**30,3%**	**1.505**	**72,1%**

TABLE 5: INFLUENCE OF IMPROVEMENTS ON CURRENT PROCESS TIME AND DISTANCE TRAVELLED

Various improvements deal with disruptions which happened during the observation period, especially in the 'Quality incoming material' and 'Correct electronic schemes' categories. These highly unpredictable events greatly affect the total process time and can disturb this analysis, because those specific events might not repeat itself. However, several employees and managers recognized that this type of events occurs during the production process of every machine. The company should be organized to decrease the frequencies of such events and to diminish their effect.

The observer was not able to differentiate the causes of unsatisfying quality of incoming material, because employees were not always aware of which supplier delivered a specific part or if the order sent to the supplier was correct. Both should therefore receive attention in the improvement effort.

The improvements will affect the time needed for each process step. Also, the percentage of Value Added Time will increase. Some (N)NVA activities seem to be inevitable after this improvement effort. This is especially due to alignment tasks and quality inspection tasks currently necessary to meet the required quality standards. The future state process times are represented in the following table.

Process step		Total	Category Process	Move	Install	Inspect	Wait
Mechanic	(min)	376,5	222,7	44,9	75,3	3,7	30,0
	(%)	100,0%	59,1%	11,9%	20,0%	1,0%	8,0%
Pneumatics	(min)	265,5	259,5	6,0	0,0	0,0	0,0
	(%)	100,0%	97,7%	2,3%	0,0%	0,0%	0,0%
Electronics	(min)	1.076,5	996,0	29,5	19,0	0,0	32,0
	(%)	100,0%	92,5%	2,7%	1,8%	0,0%	3,0%
Programming	(min)	890	360,0	2,0	528,0	0,0	0,0
	(%)	100,0%	40,4%	0,2%	59,3%	0,0%	0,0%
Total	**(min)**	**2.608,5**	**1.838,2**	**82,4**	**622,3**	**3,7**	**62,0**
	(%)	**69,7%**	**49,1%**	**2,2%**	**16,6%**	**0,1%**	**1,7%**

TABLE 6: FUTURE PROCESS TIMES, PER PROCESS STEP

A similar result can be seen in the distance travelled.

Process Step	Distance (m)
Mechanic	285,5
Pneumatics	42,0
Electronics	214,0
Programming	40,0
Total	**581,5**

TABLE 7: FUTURE STATE PROCESS, DISTANCE TRAVELLED

Process rebalancing

The takt time of 2 days prescribes that each workstation has a maximum work content of 2 days, or 960 minutes. Table 6 clearly shows that some process steps have less work content, and the Electronics steps has too much. This calls for rebalancing the production line.

It is important to understand the amount of workstations needed to fulfill the takt time as well as the total work content. This is calculated by the following formula (Rother & Harris, 2001):

$$Nr. of\ Workstations = \frac{Total\ Work\ Content}{Takt\ time}$$

The total work content, not including the Assembly step, is 2.608,5 minutes. The takt time is 960 minutes. The number of workstations should therefore be 2,7. Rother and Harris (2001) prescribe that when the remainder of the number of workstations calculation, 0,7 in this case, is higher than 0,5, the number of workstations should be rounded up. The number of workstations for Wheels Inc. should therefore be 3, all with a maximum work content of 960 minutes.

This can be achieved by combining the Mechanic and Pneumatics step and by relocating some of the work of the Electronics step to this new combination. Rother and Harris (2001) promote having all stations but one filled with work content as much as possible and to have one station with less work content. This clearly shows how much waste should be cut to decrease the number of workstations by one. However, due to the type and lengths of tasks in the production process of product C, this is not possible in this case. The process times after rebalancing will therefore be as follows:

				Category		
Workstation	**Total**	**Process**	**Move**	**Install**	**Inspect**	**Wait**
Mechanic/Pneumatics (min)	809,8	627,2	54,6	94,3	3,7	30,0
Mechanic/Pneumatics (%)	100,0%	77,5%	6,7%	11,6%	0,5%	3,7%
Mechanic (min)	376,5	222,7	44,9	75,3	3,7	30,0
Pneumatic (min)	265,5	259,5	6,0	0,0	0,0	0,0
Relocation of tasks (min)	+155,8	+145,0	+3,8	+19,0	0,0	0,0
Electronics (min)	908,8	851,0	25,8	0,0	0,0	32,0
Electronics (%)	100,0%	93,6%	2,8%	0,0%	0,0%	3,5%
Electronics (min)	1.076,5	996,0	29,5	19,0	0,0	32,0
Relocation of tasks (min)	-155,8	-145,0	-3,8	-19,0	0,0	0,0
Programming (min)	890,0	360,0	2,0	528,0	0,0	0,0
Programming (%)	100,0%	40,4%	0,2%	59,3%	0,0%	0,0%
Total (min)	**2.608,5**	**1.838,2**	**82,4**	**622,3**	**3,7**	**62,0**
Total (%)	**100,0%**	**70,5%**	**3,2%**	**23,9%**	**0,1%**	**2,4%**

TABLE 8: BALANCED PRODUCTION, PROCESS TIMES PER STEP AND CATEGORY

With this balanced process, each workstation has work content which can be covered within the takt time. The production process should therefore be able to cope with the prescribed takt time and work content. The workstation with the highest work content, Electronics, is filled for 94,7 percent of the takt time. According to Rother and Harris (2001) this percentage should not surpass 95 percent. Therefore, the effort to decrease waste and work content should remain present within the company to have slightly more room for variation.

For the Subassembly step to be fulfilled in two days, and have a maximum work content of 95 percent of the takt time, the amount of work should be reduced by 239 minutes to a total of 2.736 minutes. This is then allocated to three employees, all performing 912 minutes of work in two days.

Similarly, the distance travelled per workstation can be found in the following table:

Workstation	Distance (m)
Mechanic/Pneumatics	385,5
Mechanic	285,5
Pneumatic	42,0
Relocation of tasks	+58,0
Electronics	156,0
Electronics	214,0
Relocation of tasks	-58,0
Programming	40,0
Total	**581,5**

TABLE 9: BALANCED PROCESS, DISTANCES TRAVELLED

Value Stream Map, Future State

All proposed improvements and changes result in the following future state map. In this future process the total order cycle will be as follows. A customer finalizes an order with the sales department, which puts this order in the MRP system. The procurement manager then orders the necessary parts with various suppliers. These parts are either transported by air transportation or through the milk run, to either the blackening company or to Wheels Inc.. When all parts have arrived and a possible queue in front of the production processed is empty, the subassemblies are assembled by three employees in two days. All subassemblies are placed on two designated carts and placed close to the Assembly work station. The machine is then manufactured at the different workstations, taking two days at each station. When the structural and casing elements are taken from the supermarket, the procurement manager places a replacement order. After eight days of manufacturing inside the Dutch facility, the machine is ready for transportation to the customer.

Normally, improvements to the process are indicated in the future state map. For clarity reasons, the improvements have been omitted in this diagram.

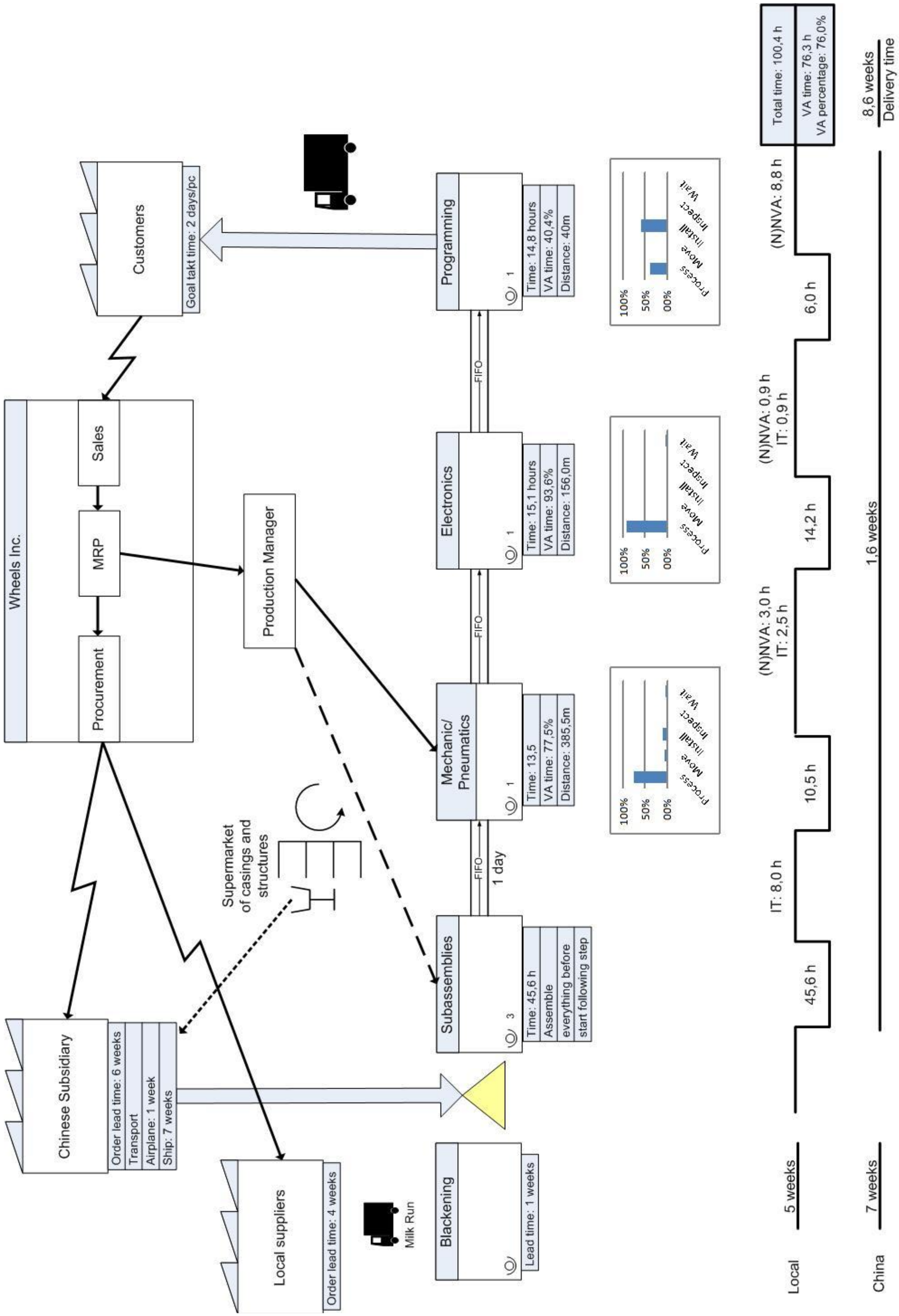

FIGURE 3: FUTURE STATE VSM

4.4. IMPLEMENTATION

Previous sections have shown improvement suggestions for the manufacturing process of product C of Wheels Inc.. This section will elaborate on the practical interventions and implementation.

There are some prerequisites which enable production at a fixed pace with continuous flow. In collaboration with different managers of Wheels Inc. the following implementation plan was developed. Each step will be discussed in some detail, including reasoning for the order of implementation and practical steps (to be) taken.

Dependable suppliers

Currently, a factor preventing paced production is poor performance of some key suppliers. These suppliers deliver parts late, in erroneous quantities and of poor quality. Due to an intimate historical relation with these suppliers and the protection of some competitive knowledge this substandard performance has been allowed the past years. To improve the quality and dependability of supplies, the following steps were, or are currently being, taken:

- A tool has been put in place to measure faulty or late deliveries and to record quality issues. The performance data will be published within the company on a regular basis as well as discussed with the respective suppliers.
- The suppliers have been notified about the concerns around their performance, and that from now on the performance will be measured and discussed with them. Contact with these suppliers has been intensified to identify problems and to instruct them more clearly.
- To depend less on this small group of key suppliers, it is currently being investigated if orders can be diverted to other suppliers, for instance to the Chinese subsidiary.

Only if the supplier issues have been sufficiently tackled it will be possible to go from the current, chaotic production process to a stable, paced process (Karlsson & Åhlström, 1996). This intervention can be seen as a supply reduction strategy as proposed by Lee (2002). It is expected that improved supplier performance will lead to the required decrease of work content in the Subassembly step.

A variation of the proposed milk run for local suppliers has been implemented, cutting that specific inventory to one week and the blackening lead time to one week as well.

Reduce the eighth waste

Through numerous talks with production employees during the observation period it became clear that the employees have many relevant ideas for improvement. However, most of these ideas are not converted into action, lowering the morale of the employee with the idea. On the other hand, the managers feel that problems are only mentioned vaguely with the expectation the managers offers instant solutions.

To support the flow from ideas on the production floor to actual action an improvement form was introduced, to be found in Appendix B. On this improvement form employees identify a problem and the solution they propose, including a rough financial implication. After handing this form in, the manager of the respective department has to report back to the employee within ten working days about whether or not the solution will be implemented and why. Every month data is published within the company about the number of proposed ideas, the percentage implemented, the percentage of ideas handled within ten working days, and a progress report for the ideas which are being implemented.

The first ideas, ranging from unblocking safety routes to improving packaging of certain parts, have been implemented. An effort will be necessary the coming months to increase the flow of ideas. As a part of this effort, the CEO will work on the production floor one day every two weeks. Each time he will work with a different employee to better understand issues and improvement possibilities throughout the entire process.

Workplace improvement

The workplace can be improved by making tools and parts easier to find, and by locating them closer to where they are needed. To achieve this, several steps are currently underway:

- The carts used to stock parts between the Subassembly and the Mechanic step will be designated to a specific order, indicated by a paper attached to the cart. Furthermore, two layers will be added to each cart to hold more parts. In this way, two designated carts can hold all subassemblies and smaller parts, like bolts, needed for one machine. This makes it easier to find the necessary parts and subassemblies. The carts will be placed close to the specific workstation, to reduce travelling distance and time.
- Together with two production employees an analysis was made of what tools are necessary per workstation to perform all the tasks. This clearly showed that their tool boxes were overly filled, making it difficult to find the right tool. Special tool tables will be made, including the tools required at a specific workstation. The tool tables will also hold specific materials necessary at the workstation, such as tubes or cables.
- Tools needed to repair incoming material, such as drill bits, will be located in the production manager’s office. This intervention makes it evident to the manager every time there are quality issues with incoming material and should lead to stricter control of supplier performance.

These improvements are currently in process to prepare the organization for a paced production process. They should be implemented before a following batch of product C will be manufactured. A paced process will be introduced with a pilot of that batch of product C and this will be followed by more improvement implementations.

Paced production (pilot)

A pilot of paced production will be done with one batch of product C. At first the pace might be slightly lower than the takt time. Lessons drawn from the first batch will serve as input for further improvements. The pilot is also a way for the employees to get used to this way of working. After the pilot, other product types with similar amounts of work content will be added to this process while maintaining the effort to reduce waste. Finally, also products with less work content will be manufactured by this process. The few products with substantially more work content will be produced in a different area of the production floor.

By also mixing lower work content machines in the queue, employees will have time to fulfill their non-production tasks, such as engineering, on a regular basis. Currently, the engineering tasks are delayed often under pressure of due dates, resulting in outdated technical drawings and electrical schemes, with connected delays in production. This extra time can also be used to write uniform and up-to-date work instructions.

Machine redesign

The final, and most long term, effort will be to redesign the total product range in such a way that it is viable to keep stock of machine casings and structures in the Dutch facility. The future state VSM gives a clear insight in the positive effect of this effort.

5. Results and Discussion

By following the proposed implementation path of the improvements, the performance of the production process can be improved. This will allow Wheels Inc. to cope with the expected increased demand with the same people using the same space. Expected results for some key parameters are presented in the following table:

Performance indicator	Current	Future	Change (%)
Process steps work content (min)	3.741,2	2.608,5	30,3%
Subassembly work content (min)	2.975	2.736	8,0%
(N)NVA percentage (%)	65,4%	24,0%	63,3%
Delivery time, max (weeks)	18,8	8,6	54,3%
Delivery time, min (weeks)	14	8,6	38,6%
In-factory lead time, max (weeks)	5,8	1,6	72,4%
In-factory lead time, min (weeks)	5	1,6	68,0%
Distance travelled (m)	2.086,5	581,5	72,1%

Table 10: Expected improvement in performance

Little's Law states that the amount of work in progress equals the lead time divided by the takt time (Little, 1961). In the current situation this results in a average work in progress of at least 6,8 machines (LT = 20 days, takt time = 2,94 days/machine). This is in line with the general image one gets by visiting the factory. In the future state this number can be reduced to 4 machines (LT = 8 days, takt time = 2 days/machine). This is a reduction of 41,2 percent.

5.1. Company discussion

The most relevant results for the company are the reduced time needed in the different process steps and the decrease delivery time. By reducing the total work content of the process, the same number of employees can build more machines. Decreasing the delivery time makes the company more responsive to customer demand and diminishes the need of forecasting demand. This reduces the risk of stock-outs or of obsolescence of parts.

Prior to the research, the management of the company set goals for these two parameters. The aim was to decrease delivery time with 50 percent and to increase productivity with 9 percent. Even though the goals were set arbitrarily, it is relevant to understand if the VSM method indicates enough improvement potential to satisfy the company.

Improvement suggestions have the potential to decrease the work content of the observed part of the process by 30,3 percent. This increases the employee productivity with the same percentage. The improvement is considerably more than aimed for and the managers were surprised by the amount of waste found within the process steps. Unexpected insights especially came from the amount of time wasted due to problems with incoming material and by walking through the facility to find tools and parts.

Further suggestions allow the delivery time to decrease substantially. The lead time within the premises of the Dutch facility can be reduced by at least 68,0 percent, mostly by implementing continuous flow. This reduces the inventory time of machines. The VSM diagrams proved to be a powerful tool to convey this message. At first, the suggestion of production in a line was countered by the argument that building machines in a batch allow for faster manufacturing, due to learning effects. If someone has, for instance, just performed the Pneumatics step at one machine, it will take less time for the following machines of that batch. This, however, does not offer an efficiency increase of 68 percent. The VSM analysis showed that a shift in mindset was needed around this topic. It intrigued the managers of the company that this result can be reached within a relatively short period with an estimated investment of less than € 2.000,--.

The total delivery time can be decreased by 38,6 percent to 8,6 weeks, taking the most favorable scenario currently possible as a benchmark. For the more common scenario, when no machine casings and structures are held in stock, the decrease in total delivery time is 54,3 percent. It can therefore be concluded that the goal for lead time reduction can be reached or at least closely approached by implementing the suggestions from this analysis.

It was insightful for the managers to see that their current process is not capable of living up to the promised delivery time of 13 weeks. Even if structural elements are held in stock, the lead time to get certain parts from local suppliers, to the blackening company and back, delays the production process too much to deliver the machines in time. The VSM diagrams also indicate that it might be beneficial to order more parts in China and fly them to the Netherlands, because the lead time for parts coming from China by plane is acceptable in the future state, while total costs are probably lower. A thorough financial analysis should be performed to determine the optimal choice. Furthermore, the VSM analysis emphasizes the advantage of redesigning machines to decrease the variety of casings and structures. A long lasting effort should be started in order to reach this.

Furthermore, it was observed that the lean initiative was welcomed by most production employees. They felt that the issues they encountered in their daily work were now recognized and that an effort was put to structurally improve the process. Their skepticism about the longevity of this effort should be overcome by perseverance. As most of the implementation is planned to happen after this research, it is not possible to understand the effect of this effort on employee satisfaction. Some employees might lose a sense of being indispensable, as more tacit knowledge is converted into explicit knowledge. Also, employees might lose some freedoms they currently have. For instance, employees are now allowed to decide how many hours they work each day, as long as they work forty hours each week. This might become problematic when producing to takt time. It is essential to manage this influence carefully.

Parallel to this Value Stream Mapping analysis a lean consultant was supporting a companywide lean effort. His implementation method was based on the fifth approach described in the Lean implementation section, starting with creating awareness, followed by 5S. It was interesting to see how this approach struggled to convince the employees of the necessity of change. It became clear that the measurements about time wasted, machines waiting, and distance travelled from this research were more appealing to the employees. The lean consultant changed his approach to one more alike a VSM analysis. It was evident that this increased employee engagement and enthusiasm.

The effect of this implementation on product quality is not taken into consideration, because the observer has no insight in the quality standards to be met. However, it is hypothesized that the introduction of standard work instructions may have a positive effect on quality performance measures.

It should be noted that most improvements do not offer a direct increase in profitability, mostly because the production staff cannot be decreased in size. Increased profitability is to be reached by ensuring the same facility is capable of coping with an increase in sales.

Finally, several discussions with management and employees allowed for confidence that the analysis focused on this specific product family can be generalized to the majority of the entire product range produced in the Dutch facility.

5.2. General discussion

In order to understand the relative value of the potential improvements the results should be compared to results attained in other cases. However, this is complicated by two main concerns. First and foremost, there are few published examples of case studies in comparable production environments to be used as a benchmark. Second, the level of potential improvements depends strongly on the initial state of the considered process. There is no clear benchmarking model to compare the initial states of different processes.

To get some indication of what is considered to be a successful lean implementation, the potential improvements at Wheels Inc. regarding lead time and productivity are compared to two measures. The goals set by Lathin and Mitchell (2001) and a somewhat similar case study (Gates, 2004).

Lathin and Mitchell (2001) claim that any traditional mass producer should be able to decrease lead time by 90 percent and increase labor productivity by 50 percent. Even though Wheels Inc. is not a mass producer these improvements serve as some indication. Gates (2004) performs a VSM analysis in a single department of a high-mix/low-volume environment, which could be considered relatively similar to Wheels Inc.. He finds a potential lead time reduction of 67 percent.

Through the proposed improvements Wheels Inc. can reduce their total delivery lead time with between 38,6 percent and 54,3 percent. The predominant cause that this falls short of the set goals is the long lead time suppliers offer. Extending the lean efforts to the suppliers can decrease the total delivery lead time of Wheels Inc. even further. The in-house lead time can be reduced by between 68 percent and 72,4 percent. This surpasses the potential found by Gates (2004) and approaches the goal set by Lathin and Mitchell (2001). Labor productivity of the observed process can be increased by 30,3 percent. This too comes within reach of the potential Lathin and Mitchell (2001) assume. It is hypothesized that the high fraction of manual labor applied in Wheels Inc. and the fact that they have no setups limits their potential improvement.

To understand if the analysis of the production of product C at Wheels Inc. offers sufficient potential the improvement potential was compared to management's expectations and to measures from the literature. Both comparisons indicate that the found potential can be considered to be substantial.

6. Conclusion and implications

This section will first answer the three sub research questions. Combining the answers for these questions will lead to a conclusion concerning the main research question of this thesis. Then the generalizability of the results will be elaborated upon, followed by a brief discussion of the academic relevance and the managerial implications of this thesis.

6.1. Research question

The purpose of this thesis was to understand if the Value Stream Mapping method is an appropriate method for Small and Medium Enterprises to become more productive and to respond more adequately to customer demand. To answer the research question, three sub research question were proposed and answered in this thesis.

First, it was essential to understand if lean thinking is applicable to SMEs. Extensive literature review gave an ambiguous answer. Based on the results lean thinking commonly yield, it seems that lean is an interesting approach for SMEs. Various investigations show that lean implementation in SMEs is less common and less extensive than in large organizations. Other research shows that while SMEs generally implement less lean methods, they benefit more in terms of productivity. Several case studies of lean implementations in SMEs show what results can be attained by implementing lean thinking. This thesis on its own is an example of potential improvements which can be revealed by lean methods. It can therefore be concluded that lean thinking is an appropriate production methodology for SMEs, at least under certain conditions.

Then, the most appropriate lean implementation method for SMEs was selected. Critical success factors for lean implementation found in the literature where translated into essential characteristics of an implementation method. Different implementation methods were described and discussed according to the essential characteristics. From this analysis VSM emerged as the most appropriate candidate. This method lacks an explicit focus on necessary cultural change. However, it was hypothesized that the clear visualization of occurrences of waste can instigate sufficient understanding among the workforce. This was indeed experienced in the performed case study.

After concluding that lean thinking can be applicable to SMEs and VSM that seems to be the most appropriate implementation method for SMEs it was investigated what results can be attained by the VSM method in an SME. It was decided to use a case study as the research strategy. This allows for detailed understanding of the implementation process and the connection to its natural context. A case company was found in one of the relevant sectors of the Dutch economy. The company meets the requirements to become lean and fits the delimitations of this study.

The VSM method was performed on the production process of a specific product family in the case company. Through informal talks and direct observation of the production process data were gathered about the entire value stream. The Process Activity Mapping tool was used to enhance the richness of the gathered data, by classifying all separate actions in different categories. During the observation period, suggestions for improvement of the process steps were recorded. Combining the recorded suggestions with the prescribed VSM analysis resulted in a proposed future state of the production process. A plan was devised to guide the implementation of the process changes.

Comparing the proposed future state with the current state gave insight in the potential improvement regarding different process parameters, such as work content, delivery time, and in-factory lead time. The revealed potential exceeded management expectations and some unexpected insights were gained. To value the relevance of the exposed potential, the gains were compared to measures found in the literature. The improvements approach goals set for traditional mass producers and exceed the potential found in a relatively similar case. Even though the used measures are far from universally accepted, the benchmark does seem to indicate that the found improvement potential is substantial.

To summarize, it can be concluded that lean can be applicable to SMEs. Furthermore, evidence is provided which supports the conclusion that VSM is the most appropriate lean implementation method for SMEs. Finally, the improvement potential found by the VSM method is substantial. Together, the conclusions for the different sub research questions lead to answering the main research question. It is concluded that Value Stream Mapping can offer a useful guidance in the quest of SMEs to become more productive and to be more responsive to customer demand.

6.2. GENERALIZABILITY

The highest level finding of this thesis can be generalized to other production SMEs; VSM can support a company in becoming more productive and more responsive to customer demand. However, the found improvement potential in terms of for instance reduction in delivery time and increase in productivity, should be regarded as specific to the case company. Similar results might not be attainable for other SMEs aiming to becoming lean. Conversely, other SMEs should possibly reach for even higher performance improvements. The results achieved in this research could serve as a benchmark for other SMEs producing machines, which have low volume demand and where manual labor is prominent.

6.3. Academic relevance

The contribution of this research to the academic literature is threefold. First, a connection is made between critical success factors of lean implementation methods to understand what method is most appropriate. This should add to the debate about how to start with lean thinking in organizations in general and specifically in SMEs. Then, the VSM technique was performed in combination with the Process Activity Mapping tool. The results shown in this thesis show the potential improvements found by this combinations of tools. This is especially relevant for future research on SMEs which depend strongly on manual activities while having low demand. Finally, this thesis adds a case study of implementing lean in SMEs. Examples in the academic literature of such case studies are lacking to fully grasp the potential for lean in SMEs.

6.4. Managerial implications

This thesis shows the potentially substantial improvements which can be revealed by applying the VSM method. The proposed changes can strengthen a company's competitive position, while requiring limited investment. The thesis shows that direct observation of the production process can expose additional potential for improvement. Managers of SMEs should investigate if lean thinking can be applied to their organization. They should not feel 'intimidated' by the association of lean thinking with large production facilities.

7. LIMITATIONS AND FUTURE RESEARCH

This final section will describe the limitations of the research and the results presented in this thesis. Furthermore, suggestions for future research will be presented.

7.1. LIMITATIONS

There are various limitations to this research. The cause of various limitations is the selected research strategy, being a combination of an extensive literature review with a case study of a single company. This limits the generalizability of the conclusions of this research to other SMEs, especially those which differ substantially from Wheels Inc.. Furthermore, the research tests only one implementation methods and it is therefore not able to compare the results to lean implementation efforts in similar organization using different implementation methods. Research which covers multiple implementation methods in a wide array of SMEs can offer more profound insight in the applicability and potential of lean in SMEs, and the effects of following different implementation approaches.

The data supporting this research was gathered by direct observation of the production process. This can limit the validity of the results, even after careful consideration of which employee to observe. The translation of the observed data to a generic process can also disturb the process information.

Finally, the revealed improvement potential is, for now, hypothetical. Some first implementation steps were made by the case company as a result of this research. Measurements of the improved process should validate the improvement potential. However, the implementation had not reached a significantly progressed state during the period available to this research.

7.2. FUTURE RESEARCH

This research also leads to suggestions for further research. The first suggestion is to increase researching the effects of lean thinking in SMEs. SMEs are an important element of Western economies and increasing their productivity would enhance the competitive position of the Western economies in the globalized market. A part of this research should be dedicated to developing stronger understanding of an optimal implementation method. Research should therefore compare instances of lean implementation using different implementation methods to understand advantages of disadvantages or different approaches. To support this research, a framework should be developed which allows to rank the ‘leanness’ of the initial state of each case. This allows for better benchmarking between cases.

Also, more research should be done on how to sustain the use of lean methods and how to translate this into lasting competitive advantage. A generic method to calculate the financial implications of a lean effort could help to increase the dissemination of lean implementation.

Other areas of research which currently remain relatively untapped are how lean thinking can be implemented in SMEs offering services. Especially lean in micro service enterprises, having less than ten employees, have been left out of scope of the academic literature.

Furthermore, more insight should be gained in how implementing lean thinking affects employee well being and satisfaction in SMEs. The employee dynamics in a small organization might differ from the dynamics in large organization. To ensure long lasting benefits from lean implementation, employee satisfaction should be understood and managed carefully.

Finally, in conversations with different companies, it became clear that there is a lack of understanding what improvement philosophy, for instance lean, TOC, or SixSigma, is most appropriate for the most pressing issues of a company. As all of these philosophy aim for improved flow of products, a ‘Flow manufacturing’ philosophy could be developed. This philosophy could combine the three mentioned philosophy into one. This would also decrease the polarization between supporters of different philosophies.

8. Attachments

A. Observation form

	Machine number:									
#	Step	Time (min)	Distance (m)	# People	Process	Move	Install	Inspect	Wait	Remarks and suggestions for improvement

B. Improvement form (translated)

Name:	Department:	Date:
Problem:		
It should be like this: Try to give an estimate of the financial implications		
This saves: (Min/pieces/etc) per (machine/day/week/month/year)		

To be filled out by the manager of the respective department

Element	**Yes/No**	**Remarks**
Problem and solution: Is the problem recognized? Will the problem be eliminated by the idea? Are there alternative solutions?		
Financial: Is an investment needed? If yes, are the financial estimates about costs and benefits correct? Will the investment be recovered in one year?		*If the recovery period exceeds one year, it should be discussed in more detail.*
Effect on others: Does the idea affect others, positively or negatively?		
Decision: Will the idea be carried out?		

Was the idea discussed individually within ten working days?

9. References

Abdulmalek, F. A., & Rajgopal, J. (2007). Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. *International Journal of Production Economics, 107*(1), 223-236.

Abernathy, W. J., Clark, K. B., & Kantrow, A. M. (1981). The new industrial competition. *Harvard Business Review, 59*(5), 68-81.

Achanga, P., Shehab, E., Roy, R., & Nelder, G. (2006). Critical success factors for lean implementation within SMEs. *Journal of Manufacturing Technology Management, 17*(4), 460-471.

Adler, P. S., & Cole, R. E. (1993). Designed for learning: a tale of two auto plants. *Sloan Management Review, 34*(3), 85-95.

Åhlström, P. (1998). Sequences in the implementation of lean production. *European Management Journal, 16*(3), 327-334.

Allen, R. K. (1997). Lean and mean: workforce 2000 in America. *Journal of Workplace Learning, 9*(1), 34-42.

Baker, P. (2002). Why is lean so far off. *Works Management, 55*(10), 26.

Bhasin, S., & Burcher, P. (2006). Lean viewed as a philosophy. *Journal of Manufacturing Technology Management, 17*(1), 56-72.

Bisson, P., Stephenson, E., and Viguerie, S.P. (2010). The Productivity Imperative. *McKinsey Quarterly, June*.

Campbell, D. T., Stanley, J. C., & Gage, N. L. (1963). *Experimental and quasi-experimental designs for research*: Houghton Mifflin Boston.

CNNMoney (2011). Global 500 companies by country Retrieved 18-3-2012, from http://money.cnn.com/magazines/fortune/global500/2011/

Conner, G. (2009). *Lean manufacturing for the small shop*: SME.

Conti, R., Angelis, J., Cooper, C., Faragher, B., & Gill, C. (2006). The effects of lean production on worker job stress. *International Journal of Operations & Production Management, 26*(9), 1013-1038.

Corboy, M., & O'Corrbui, D. (1999). The seven deadly sins of strategy. *MANAGEMENT ACCOUNTING-LONDON-, 77*, 29-31.

de Souza, L. B. (2009). Trends and approaches in lean healthcare. *Leadership in Health Services, 22*(2), 121-139.

Detty, R. B., & Yingling, J. C. (2000). Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study. *International Journal of Production Research, 38*(2), 429-445.

Dun & Bradstreet (2011). Flinke stijging aantal faillissementen in mei. Retreived 19-3-2012, from http://www.dnb-nederland.nl/over-dnb/nieuws/?messageID=19

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of management review*, 532-550.

Elliott, G. (2001). Achieving Manufacturing Excellence. *Industrial Management*(May), 2-7.

Ellram, L. M. (1996). The use of the case study method in logistics research. *Journal of Business Logistics, 17*(2), 93-138.

Emiliani, B. (2009). The Equally Important "Respect for People" Principle.

Emiliani, B., Stec, D. J., Grasso, L., & Stodder, J. (2003). *Better thinking, better results: Using the power of lean as a total business solution*: Center for Lean Business Managemnt.

Emiliani, B., & Stec, D. (2004). Using value-stream maps to improve leadership. *Leadership & Organization Development Journal, 25*(8), 622-645.

Engineering Employer’s Federation. (2001). Catch up with uncle Sam: the EEF final report on US and UK manufacturing productivity. (December), 4-41.

European Commission. (2012). Fact and figures about the EU´s Small and Medium Enterprise Retrieved 18-3-2012, from http://ec.europa.eu/enterprise/policies/sme/facts-figures-analysis/index_en.htm

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative inquiry, 12*(2), 219.

Fujimoto, T. (1999). *The evolution of a manufacturing system at Toyota*: Oxford University Press, USA.

García-Teruel, P. J., & Martínez-Solano, P. (2007). Effects of working capital management on SME profitability. *International Journal of Managerial Finance, 3*(2), 164-177.

Gates, M. D. (2004). *Lean manufacturing system design and value stream management in a high-mix, low-volume environment.* Massachusetts Institute of Technology, Sloan School of Management; and,(SM)--Massachusetts Institute of Technology, Department of Mechanical Engineering; in conjunction with the Leaders for Manufacturing Program at MIT.

Gerring, J. (2004). What is a case study and what is it good for? *American Political Science Review, 98*(2), 341-354.

Gillham, B. (2000). *Case study research methods*: Continuum Intl Pub Group.

Goh, A. L. S. (2006). Evolution of industrial policy-making in support of innovation: the case of Singapore. *International Journal of innovation and Learning, 3*(1), 110-125.

Goldratt, E., & Cox, J. (1984). The goal: an ongoing improvement process. *Gower, Aldershot*.

Grewal, C. (2008). An initiative to implement lean manufacturing using value stream mapping in a small company. *International Journal of Manufacturing Technology and Management, 15*(3), 404-417.

Hall, R. (2004). Lean and the Toyota production system. *Target, 20*(3), 22-27.

Hayes, R., Pisano, G., Upton, D., & Wheelwright, S. (2005). *Pursuing the competitive edge: Operations, strategy and technology*: New York: Wiley.

Hayes, R. H., Wheelwright, S. C., & Clark, K. B. (1988). Dynamic manufacturing: Creating the learning organization.

Hayes, R. H., & Wheelwright, S. G. (1979). The dynamics of process-product life cycles. *Harvard Business Review, 57*(2), 127-136.

Hines, P., Francis, M., & Found, P. (2006). Towards lean product lifecycle management: A framework for new product development. *Journal of Manufacturing Technology Management, 17*(7), 866-887.

Hines, P., & Lethbridge, S. (2008). New development: Creating a lean university. *Public Money and Management, 28*(1), 53-56.

Hines, P., & Rich, N. (1997). The seven value stream mapping tools. *International Journal of Operations & Production Management, 17*(1), 46-64.

HMSO (1978). *Second Report form the Select Committee on Science and Technology: "Innovation, Research and Development in Japanese Science-based Industry"*. London.

Holweg, M. (2007). The genealogy of lean production. *Journal of Operations Management, 25*(2), 420-437.

Hopp, W. J., & Spearman, M. L. (2008). *Factory physics*: McGraw-Hill Irwin Irwin.

Jones, D. T., & Womack, J. P. (2002). *Seeing the whole: mapping the extended value stream*: Productivity Press.

Karlsson, C., & Åhlström, P. (1995). Change processes towards lean production: the role of the remuneration system. *International Journal of Operations & Production Management, 15*(11), 80-99.

Karlsson, C., & Åhlström, P. (1996). Assessing changes towards lean production. *International Journal of Operations & Production Management, 16*(2), 24-41.

Karmarkar, U. S. (1987). Lot sizes, lead times and in-process inventories. *Management science*, 409-418.

Kessler, W. (1999). Implementing lean thinking. *Inf Knowledge Syst Manage, 1*(2).

Klefsjö, B., Wiklund, H., & Edgeman, R. L. (2001). Six Sigma seen as a methodology for total quality management. *Measuring Business Excellence, 5*(1), 31-35.

Krafcik, J. F. (1986). Learning from NUMMI. *IMVP Working paper. Massachusetts Institute of Technology*.

Krafcik, J. F. (1988b). Triumph of the lean production system. *Sloan Management Review, 30*(1), 41-52.

Kumar, M., Antony, J., Singh, R., Tiwari, M., & Perry, D. (2006). Implementing the Lean Sigma framework in an Indian SME: a case study. *Production Planning and Control, 17*(4), 407-423.

Landsbergis, P. A., Cahill, J., & Schnall, P. (1999). The impact of lean production and related new systems of work organization on worker health. *Journal of Occupational Health Psychology, 4*(2), 108.

Lasa, I. S., de Castro, R., & Laburu, C. O. (2009). Extent of the use of Lean concepts proposed for a value stream mapping application. *Production Planning & Control, 20*(1), 82-98.

Lathin, D., & Mitchell, R. (2001). Lean manufacturing. *American Society for Quality Journal*, 2-9.

Lee, H. L. (2002). Aligning supply chain strategies with product uncertainties. *California management review, 44*(3), 105-119.

Lee, H. L., Padmanabhan, V., & Whang, S. (1997). Information distortion in a supply chain: the bullwhip effect. *Management science*, 546-558.

Liker, J. K. (1997). *Becoming lean: Inside stories of US manufacturers*: Productivity Pr.

Little, J. D. C. (1961). A Proof for the Queuing Formula: L= l W. *Operations research*, 383-387.

Manoochehri, G. (1988). JIT for small manufacturers. *Journal small business management*.

Mastroianni, R., & Abdelhamid, T. (2003). *The challenge: The impetus for change to lean project delivery*.

Mehri, D. (2006). The darker side of lean: An insider's perspective on the realities of the Toyota Production System. *The Academy of Management Perspectives ARCHIVE, 20*(2), 21-42.

Miles, M. B. (1979). Qualitative data as an attractive nuisance: The problem of analysis. *Administrative science quarterly, 24*(4), 590-601.

Monden, Y. (1998). *Toyota Production System, An Integrated Approach to Just-In-Time, Norcross, GA: Engineering & Management Press*: ISBN 0-412-83930-X.

Needy, K., Norman, B. A., Bidanda, B., Ariyawongrat, P., Tharmmaphornphilas, W., & Warner, R. C. (2002). Assessing human capital: A lean manufacturing example. *ENGINEERING MANAGEMENT JOURNAL-ROLLA-, 14*(3), 35-39.

Ohno, T. (1988). *Toyota production system: beyond large-scale production*: Productivity Pr.

Pavnaskar, S., Gershenson, J., & Jambekar, A. (2003). Classification scheme for lean manufacturing tools. *International Journal of Production Research, 41*(13), 3075-3090.

Piercy, N., & Rich, N. (2009). Lean transformation in the pure service environment: the case of the call service centre. *International Journal of Operations & Production Management, 29*(1), 54-76.

Poppendieck, M. (2007). *Lean software development*.

Porter, M. E. (1979). *How competitive forces shape strategy*: Abril.

Portioli Staudacher, A., & Tantardini, M. (2010). Lean Production implementation: a survey in Italy. *Dirección y Organización*(35), 52-60.

Prabhu, V. (1992). Lean Production and the Single European Market. *UMIST, Manchester*.

Productivity Press. (2002). *Pull production for the shop floor*: Productivity Press, Development Team.

Rabobank (2009). Dutch Industrial Sector Hit Hardest by Recession Retrieved 01-06-2012, from https://www.pressroomrabobank.com/publications/economy/dutch_industrial_sector_hit_hardest_by_recession.html

Ries, E. (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*: Crown Business.

Rose, A. N. M., Deros, B. M., & Rahman, M. N. A. (2009). A REVIEW ON LEAN MANUFACTURING PRACTICES IN SMALL AND MEDIUM ENTERPRISES.

Rother, M., & Harris, R. (2001). Creating continuous flow. *The Lean Enterprise Institute, Massachusetts, USA*.

Rother, M., & Shook, J. (2003). *Learning to see: value stream mapping to create value and eliminate muda*: Productivity Press.

Scherrer-Rathje, M., Boyle, T. A., & Deflorin, P. (2009). Lean, take two! Reflections from the second attempt at lean implementation. *Business Horizons, 52*(1), 79-88.

Shah, R., & Ward, P. T. (2003). Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management, 21*(2), 129-149.

Shah, R., & Ward, P. T. (2007). Defining and developing measures of lean production. *Journal of Operations Management, 25*(4), 785-805.

Sheridan, J. (2000). Growing with lean. *Industry Week, 249*(16), 32-36.

Sim, K. L., & Rogers, J. W. (2008). Implementing lean production systems: barriers to change. *Management Research News, 32*(1), 37-49.

Singh, B., & Sharma, S. (2009). Value stream mapping as a versatile tool for lean implementation: an Indian case study of a manufacturing firm. *Measuring Business Excellence, 13*(3), 58-68.

Smith, B. (2003). Lean and Six Sigma-a one-two punch. *Quality progress, 36*(4), 37-41.

Sohal, A. S., & Egglestone, A. (1994). Lean production: experience among Australian organizations. *International Journal of Operations & Production Management, 14*(11), 35-51.

Soriano-Meier, H., & Forrester, P. L. (2002). A model for evaluating the degree of leanness of manufacturing firms. *Integrated Manufacturing Systems, 13*(2), 104-109.

Spear, S., & Bowen, H. K. (1999). Decoding the DNA of the Toyota production system. *Harvard Business Review, 77*, 96-108.

Spear, S. J. (2004). Learning to lead at Toyota. *Harvard Business Review, 82*(5), 78-91.

Stock, G. N., Greis, N. P., & Kasarda, J. D. (1999). Logistics, strategy and structure: a conceptual framework. *International Journal of Physical Distribution & Logistics Management, 29*(4), 224-239.

Sugimori, Y., Kusunoki, K., Cho, F., & Uchikawa, S. (1977). Toyota production system and kanban system materialization of just-in-time and respect-for-human system. *The International Journal of Production Research, 15*(6), 553-564.

Timco, D. (2001). LEARNING TO THINK LEAN: LEAN MANUFACTURING:'BEEN THERE, DONE THAT'. *Automotive Production, 113*(5), 80.

Timme, S. G., & Williams-Timme, C. (2003). The Real Cost of Holding Inventory. *SUPPLY CHAIN MANAGEMENT REVIEW, V. 7, NO. 4 (JULY/AUG. 2003), P. 30-37: ILL*.

Turfa, P. (2003). Wise potato chips factory embraces lean philosophy. *Tribune Business News, 9*, 1-4.

Vasilash, G. (2000). How Toyota does it. *Automotive Manufacturing and Production, 2000*, 1-8.

Vinodh, S., Arvind, K., & Somanaathan, M. (2010). Application of value stream mapping in an Indian camshaft manufacturing organisation. *Journal of Manufacturing Technology Management, 21*(7), 888-900.

Voss, C. (1995). Operations management "from Taylor to Toyota" and beyond? *British Journal of Management, 6*, S17-S29.

White, R. E., Pearson, J. N., & Wilson, J. R. (1999). JIT manufacturing: a survey of implementations in small and large US manufacturers. *Management science*, 1-15.

Wilson, R., & Delaney, R. (2001). *12th Annual State of Logistics Report*: National Press Club, Washington, DC.

Womack, J. P., & Jones, D. T. (2003). *Lean thinking: banish waste and create wealth in your corporation*: Simon and Schuster.

Womack, J. P., & Jones, D. T. (2005). Lean consumption. *Harvard Business Review, 83*(3), 58-68.

Womack, J. P., Jones, D. T., & Roos, D. (1990). *The machine that changed the world: based on the Massachusetts Institute of Technology 5-million dollar 5-year study on the future of the automobile*: Scribner.

Worley, J., & Doolen, T. (2006). The role of communication and management support in a lean manufacturing implementation. *Management Decision, 44*(2), 228-245.

Yin, R. K. (1981). The case study crisis: Some answers. *Administrative science quarterly, 26*(1), 58-65.

Zimmer, L. (2000). Get lean to boost profits. *Forming and fabricating, 7*(2), 36-44.