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Improving material flow and production layout using Value Stream Mapping

A case study in a manufacturing company

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Abstract

The movement and handling of material are necessary activities, however, commonly regarded as waste. Moving and handling material more times and over longer distance than necessary is time consuming, costly and unproductive. Therefore, a suitable material handling (MH) system with appropriate facility layout is advocated.

The purpose of this thesis is to explore options for material flow improvements and handling of material in production area. This comprises of a study of the material flow from storage to production areas and the handling of material in production section A. If necessary for improvements of material flow, a change in layout design will be recommended. The research approach for this thesis is a case study where data has been collected from documents, observations and interviews. The study shows that 9 % of the production time of one article is spent on manual material handling (MMH). These activities are classified as both waste and necessary, however not adding any value. The same applies for the material flow. Unnecessary distances of movements are caused by the current location of storage, operations and lack of proper structure for handling and moving material.

The contribution of this study is a list of suggestions for improving the material flow and handling. Changes for improvements are, namely, availability of appropriate equipment, storing materials closer to the operations and investing in automation and vision systems with cameras or robots. The material flow and the way the material is handled can further be improved by a change in the layout of the production area. Connecting and rearranging operations can shorten and ease the movement of material with ample space to handle the material.

Keywords

Facility layout, Material flow, Material handling, Manual material handling (MMH), Lean manufacturing, Value stream mapping (VSM), Improvement

Table of contents

1	Introduction	1
1.1	Company background.....	2
1.2	Problem description.....	2
1.3	Purpose and research questions	3
1.4	Delimitations	3
1.5	Outline	4
2	Theoretical background.....	5
2.1	Facility layout	5
2.2	Material handling.....	5
2.3	Lean manufacturing	8
2.4	Value Stream Mapping (VSM).....	10
2.5	Summary of theory	12
3	Method and implementation.....	14
3.1	Research design	14
3.1.1	Case study	14
3.1.2	Data collection techniques	14
3.2	Research process.....	16
3.2.1	Literature overview	16
3.2.2	Study at case company	16
3.2.3	Data analysis	17
3.3	Reliability and validity	18
4	Findings and analysis	19
4.1	The study of process flow.....	19
4.2	The identification of waste	22
4.3	Analysis of process flow.....	23
4.3.1	Re-evaluation for a better process sequence	25
4.3.2	Re-evaluation for a better flow pattern, layout and transport routing	25
4.3.3	Re-evaluation of activities.....	27
4.4	Future state suggestions.....	27
4.4.1	List of suggested changes for improvements	28
5	Discussion	30
5.1	Discussion of method	30

Table of contents

5.2	Discussion of findings and analysis.....	30
5.2.1	How can the movement of material from storage to production areas be improved? (RQ1).....	30
5.2.2	In what way can the material handling be improved? (RQ2).....	31
5.2.3	Can a change in the layout of the production area result in improved flow and handling of material? (RQ3)	32
6	Conclusions	34
6.1	Future research	34
7	References	36
8	Appendices	38
	Appendix A: Production layout	38
	Appendix B: Interview questions operators	39
	Appendix C: Activities during production process	40
	Appendix D: VSM of material flow	41
	Appendix E: Future state of activities during production process	42
	Appendix F: Future state of the VSM of material flow	43

List of tables

<i>Table 1: Overview of respondents interviewed at case company (n=number of respondents)</i>	16
<i>Table 2: Overview of respondents of interviews conducted</i>	17
<i>Table 3: Time spent on material handling in relation to production time</i>	22

List of figures

Figure 1: Spaghetti chart for movements of material.....	19
Figure 2: Change of process sequence for improved movements of material	25
Figure 3: Change in layout for improved material flow.....	26
Figure 4: Connecting operations for improved movements of material	27

1 Introduction

This chapter consists of a background description to the research conducted, LEAX Skaraborg AB, the problem identified, and the purpose and aim of this thesis.

There is a pressure on manufacturing companies to optimize their production related to lowering costs and increasing productivity (Denkena, et al., 2014). The way material is monitored and managed impacts the costs (Christopher, 2011), an inappropriate way increases costs and as well as decreases productivity (Hassan, 2010). The facility layout impacts the manufacturing costs and a company's productivity (Drira, et al., 2007), where a mismatch between facility layout and the way materials are moved and handled can be devastating (Aiello, et al., 2002; Drira, et al., 2007). The flow of material in manufacturing processes is of great importance in order to meet customer demand on time and maintain customer satisfaction (Green, et al., 2010), remaining competitive and increasing the productivity of the company (Rouwenhorst, et al., 2000). The aim of material flow is that it should be continuous and synchronous. Continuous entails that the flow should have no interruptions and no unnecessary inventories. Synchronous means running smooth at the same pace (Harrison, et al., 2014). Therefore, an efficient material handling system is crucial, which results in increased productivity (Green, et al., 2010).

Material handling can be costly and is regarded as a non-value adding function, however necessary (Green, et al., 2010). Green et al. (2010) argue that it can be resource intense to store and move material, both concerning equipment needed, and manpower required. Manual material handling (MMH) involves activities where lifting, lowering, carrying, pushing and pulling are performed manually, and these activities are very common in manufacturing (Deros, et al., 2015). The advantage of MMH is according to Deros et al. (2015) its flexibility and lower costs when handling lighter material, compared to material handling using mechanical equipment and machines. However, the disadvantage of MMH, when not performed accordingly or the products are too heavy, is risk of injuries of employees. Deros et al. (2015) state that incorrect motions of MMH increases risk of musculoskeletal disorders (MSDs) and lower back pain when performed repetitively and over an extended period.

Lean manufacturing is a term referring to continuous efforts to reduce and eliminate waste for a smoother flow (Seth & Gupta, 2005). Lean manufacturing is a manufacturing concept that can increase the productivity of a company (Green, et al., 2010). The fundamental of lean manufacturing, as stated by Green et al. (2010) is to reduce and eliminate waste from production processes. Ergonomics and safety aspects are also considered (Green, et al., 2010). When waste, in terms of overproduction, waiting, transporting, inappropriate processing, unnecessary inventory, unnecessary motions, and defects (Hines & Rich, 1997) are reduced, it is possible to achieve an even and synchronous flow (Harrison, et al., 2014).

Operations can be classified into three categories, non-value adding (NVA), necessary but non-value adding (NNVA) and value adding (VA) (Hines & Rich, 1997; Seth & Gupta,

2005). Waste is NVA as it adds no value; however, it consumes resources (Seth & Gupta, 2005). According to Green et al. (2010) a functional lean manufacturing in a company can have great positive impact on the material handling, since waste and non-value adding processes are reduced in favour of value adding processes (Harrison, et al., 2014).

Prior to optimization (Denkena, et al., 2014), and reducing or eliminating waste (Harrison, et al., 2014), the current state's need for improvements has to be identified. The problem can be that data required is stored in different places and systems, and it can therefore be difficult and time consuming to collect the data required (Denkena, et al., 2014).

The focus of manufacturing companies in adopting the lean methodology demands them to find new ways to identify and eliminate waste (Seth & Gupta, 2005). According to Harrison et al. (2014) this usually includes some type of technique of mapping the process. One such technique is Value Stream Mapping (VSM) (Seth & Gupta, 2005), which maps the flow of material and information to identify and eliminate waste. VSM helps visualize the processes and flows, where data such as cycle time, manpower and work in progress et cetera becomes clear for everyone (Seth & Gupta, 2005). There are various lean tools in application, such as Poka Yoke, standardized work, Kaizen, workplace organisation, which support VSM (Feld, 2001; Seth & Gupta, 2005).

Value stream includes the parts and actions that add value to the product or service produced, only for value adding processes (Hines & Rich, 1997). Using tools to identify value streams can enable manufacturing companies identifying and removing, or at least reducing waste, in processes. Removing wastes results in smoother flows (Hines & Rich, 1997) and increased productivity (Denkena, et al., 2014).

1.1 Company background

The project is carried out in collaboration with LEAX Skaraborg AB at their production facility located in Falköping, in the south west of Sweden. LEAX performs machining of casted iron, steel and aluminium, where its main customers belong to the automotive industry. At the facility in Falköping, the production runs all day over three shifts in production section A and over four and five shifts in other production sections. The products vary in sizes and production quantities, from a high volume of 2 000 000 units per year to a couple of thousand units. The processes of high volume serial production are highly automated, while lower volume production is of semi-automated or manual methods.

1.2 Problem description

Movement of material from storage to production area is found to be problematic due to unnecessary movement and additional storage of materials. The material flow is not well designed and therefore time and resources are wasted in material handling. The main area of concern of material handling is in production section A (see Appendix A). The manual

handling of materials between every station is time consuming and at times unnecessary. This can further harm the workers who are continuously moving heavy materials. For instance, one material could be lifted 60 000 times in a week over three shifts.

The inappropriate way of moving and handling material in production section A depends on the design of the layout. The area between and around the machines does not support an efficient material handling or flow. There is a lack of equipment and space to handle and move materials. There are three operators working in production section A who at times are idle, which contributes to wastage. However, handling more material during one shift is not encouraged due to risk of injuries. LEAX's intention is to find ways to improve the material flow and the layout of the production area.

1.3 Purpose and research questions

The purpose of this thesis is to explore options for material flow improvements and handling of material in production area. This comprises of a study of the material flow from storage to production areas and the handling of material in production section A. If necessary for improvements of material flow, a change in layout design will be recommended.

The material flow is improved by reducing the movement and handling of materials or reducing the distance of movement. Improvements of production area can be achieved through an efficient layout. This thesis shall aim to propose an efficient layout and material handling for improvement purposes. The following research questions shall address the thesis purpose.

RQ1: How can the movement of material from storage to production areas be improved?

Upon analysing the material movement, non-value added activities could be identified and removed. An improved material flow can then enable improvements of material handling.

RQ2: In what way can the material handling be improved?

The improvement of material flow and the way the material is handled might suggest a change in layout, therefore RQ3 aims to investigate this.

RQ3: Can a change in the layout of the production area result in improved flow and handling of material?

Answering these questions will find ways to improve the flow and handling of materials with an appropriate layout of the facility.

1.4 Delimitations

The analysis of material flow and production areas at LEAX Skaraborg AB will be limited to one specific production section; production section A. Limiting to one sector of production will allow a more in depth and comprehensive analysis.

The material flow and handling of material will only be studied during the dayshift. The analysis of material flow and handling will be conducted on one high volume article, henceforth called article B. Areas for improvements will be based on the VSM conducted, where improvements are achieved through reduction of NNVA and NVA activities.

1.5 Outline

The thesis consists of five main chapters. Chapter two contains the theoretical background where theory, concepts and tools are described for research topic of this thesis. The following chapter consists of an explanation of the methodology with methods and techniques used for data collection. In the next chapter, the findings from the study of current state of material flow and handling is presented. In the same chapter, the analysis of findings is presented, followed by suggestions of future state with a proposal of a new VSM and changes of layout. The discussion of method and findings in connection to the theory is presented in chapter five. The final chapter consists of conclusions of the study, including suggestions for future research.

2 Theoretical background

This chapter consists of a theoretical background including facility layout, material handling, lean manufacturing and VSM, followed by a summary of the theory.

2.1 Facility layout

Companies are constantly aiming for improvements, being cost efficient and meeting customers' expectations (Mathisson-Öjmertz, 1998b). Logistics operations need to be efficient to enable a company's competitiveness in a market with a wide product variety and short response times (Rouwenhorst, et al., 2000). This increases the pressure on manufacturing companies to optimize their production by lowering costs and increasing productivity (Denkena, et al., 2014), where the costs of logistics operations is a part of the overall production costs (Rouwenhorst, et al., 2000). The costs are dependent on inventory and the way material is monitored and managed (Christopher, 2011). Depending on the layout of the facility there will be different costs related to manufacturing, work in progress, productivity and lead times (Drira, et al., 2007). The efficiency of material flow and handling is also affected by the layout of the facility (Aiello, et al., 2002).

A facility layout can, according to Drira et al. (2007) relate to the arrangement and location of a production group or manufacturing cell where production of goods or services are performed. Designing a facility layout is a complex task for two reasons; the constraints of the facility and its necessity to support and ease the materials handling and movement (Mulcahy, 1999). In a manufacturing system there can be different types of layout problems, often related to the location of facilities, for instance machines, in a plant. Finding a suitable location of facilities will increase the efficiency of operations as well as reducing its expenses (Drira, et al., 2007).

The best design of a layout should, according to Drira et al. (2007), be a combination of the most efficient related to the interaction of different facilities, such as production units, and the material handling system. The expenses of the material flow are assumed to be related to the number of times materials are moved, and the distance; increased movement leads to increased expenses (Aiello, et al., 2002). Production units should be placed so that the available space is highly utilized and that the location of machines and production groups should bring as low costs of material handling and slack area as possible in order to be optimized and increase efficiency (Drira, et al., 2007). The layout should also suit the material handling system and the material flow through and between facilities (Aiello, et al., 2002; Drira, et al., 2007), since the shape of the facility impacts on the efficiency of the movement of material and the materials handling system (Mulcahy, 1999).

2.2 Material handling

Material handling is concerned with moving material (Green, et al., 2010), either by human or machine (Mulcahy, 1999). Material flow is a term describing the physical flow of material

and the way it is moved and transported (Harrison, et al., 2014). Mulcahy (1999) argues that the materials handling and movement should support an effective material flow throughout the whole facility. The design of material handling and flow should ensure low operating costs (Mulcahy, 1999), an efficient flow of material (Mathisson-Öjmertz, 1998b) with a maximum of volume handled (Mulcahy, 1999). Green et al. (2010) describe the importance of a well-working flow of material in manufacturing processes in order to meet customer demand on time and maintain customer satisfaction. Therefore, the choice of a suitable material handling system is very important, which can increase productivity (Green, et al., 2010) and reduce the total manufacturing costs (Drira, et al., 2007). “Materials handling is a system or combination of methods, facilities, labour, and equipment for moving, packaging, and storing of materials to meet specific objectives” (Öjmertz, 1998, p. 6). According to Mulcahy (1999) reduces a proper structured way of handling and moving material unnecessary double handling over the same path, lowers waiting time for machines and employees, reduces damage of products and equipment, and injuries of employees.

Material handling can be costly and is regarded as a non-value adding function (Green, et al., 2010), however necessary to ensure that material is delivered to the appropriate location (Drira, et al., 2007) at required time (Mathisson-Öjmertz, 1998b). A material handling activity can be value-adding, as stated by Mathisson-Öjmerts (1998a) “an activity has a value-adding component if it contributes to the materials approaching the state desired in the final position...” (Mathisson-Öjmertz, 1998a, p. 5), why it should not only be regarded as waste (Öjmertz, 1998). Öjmertz (1998) argues however that not all materials handling activities add value and that those activities should be reduced. Therefore, as stated by Mathisson-Öjmertz (1998a), there is a need to distinguish between time spent on value-adding activities and wasted on non-value adding where all non-value-adding activities can be regarded as waste. The difficulty with dividing activities into value adding and non-value adding is however that materials handling is regarded as non-value adding, nevertheless a necessary activity to support the production of products (Mathisson-Öjmertz, 1998a).

Green et al. (2010) argue that storing and moving material can be resource intense, both concerning equipment needed, and manpower required. Resources spent on materials handling can be a third of a product’s total cost and consume huge amount of time (Öjmertz, 1998). Öjmertz (1998) states that an efficient materials handling can therefore be a competitive advantage with lower costs and less time spent. The supply of materials inside a manufacturing company can be challenging due to the usually limited space available (Domingo, et al., 2007). Domingo et al. (2007) argue that, therefore not enough material can be stored close to the operations, which increases storage and movement of material. Finding a suitable way to handle the material can help overcoming this problem (Domingo, et al., 2007). An accurate and well-designed material handling (MH) system can effectively support operations (Hassan, 2010), where improvements of materials handling is achieved by either improving the current system or reducing number of necessary steps such as using forklifts, automated handling equipment and lifting aids for manual handling (Öjmertz, 1998). Hassan (2010) argues that a MH system not working properly can result in higher costs due to

unnecessary movements with risk of increased production times where customers might receive products too late. An optimization and a well-designed MH system can therefore reduce costs and time spent moving and handling material and increase the productivity (Green, et al., 2010; Hassan, 2010) with higher quality of products (Hassan, 2010). The risk of damage to materials is also lowered when handled fewer times (Öjmertz, 1998).

When selecting suitable MH equipment there are many factors to be considered, such as the complexity of designing a MH system, what its purpose and functions are, its life-cycle and surrounding environment (Hassan, 2010) and its appropriateness in relation to the facility layout (Drira, et al., 2007). Hassan (2010) describes designing a MH system as a complex task involving human, hardware and software aspects to consider as they together constitute and perform MH activities. The amount of different types of sub-systems of equipment complicates the process even more (Hassan, 2010). To understand the efficient usage of resources, single activities and their relationships must be understood (Mathisson-Öjmertz, 1998b). Workstations and MH systems are parts of a manufacturing system (Sukhota & Peters, 2012). Decisions taken concerning facility design have, according to Sukhota and Peters (2012), impact on the MH between workstations. An optimization of the facility layout and the design of MH system separately can lead to a manufacturing system that, as a whole system, is far from optimized (Aiello, et al., 2002). Aiello et al. (2002) therefore suggest an integrated approach to designing facility layout and MH system. When designing the facility, aspects of the MH system should be considered (Aiello, et al., 2002; Sukhota & Peters, 2012).

The purpose of a MH system is to deliver the right material where and when it is needed and in the right quantities (Hassan, 2010). MH involves actions such as moving, lifting, lowering, carrying, pushing and pulling, loading and unloading material (Deros, et al., 2015; Hassan, 2010). In manual material handling (MMH) these activities are performed manually, a common situation in manufacturing environment (Deros, et al., 2015). Deros et al. (2015) state the advantage of MMH as its flexibility and its lower costs when handling lighter material, compared with mechanical equipment and machines. The disadvantage with MMH is however if performed incorrectly or if the products are too heavy, workers risk getting injured.

Deros et al. (2015) state that the most common reason workers get musculoskeletal disorders (MSDs) and lower back pain (LBP) are results of MMH, where problems can occur on lower back, spinal injuries and inflammations. The design of materials flow and handling impacts the physical work load of employees (Öjmertz, 1998), working conditions, movements, working posture and the safety of workers (Bohgard, et al., 2009). According to Bohgard et al. (2009) can bad working posture, technique and pace harm and injure workers with risk for MSDs. Öjmertz (1998) states that injuries to industrial workers are due to poor performed MMH, especially manual lifting. The main reason these problems and injuries occur is due to over a longer time performing repetitively static loads (Deros, et al., 2015). The study conducted by Deros et al. (2015) shows quite low awareness amongst workers about ergonomics. Ergonomics benefits both the individual and the company by reduced number of

injuries and risk of accidents owing to safer working environment and increased comfort, which benefits the company with increased productivity and quality (Bohgard, et al., 2009). Ergonomics should therefore be considered while streamlining the materials flow and handling, since it can harm workers by physical work load, increase costs and lower the efficiency (Öjmertz, 1998). Managers should take the responsibility to inform their workers for them to be able to use correct MMH actions and therefore also lowering the risks of injuries in the future, since injuries do not only affect the workers and their lives. Reduced productivity and motivation of the workers are common consequences (Deros, et al., 2015), why the workplace should be designed for safety and ergonomics with an adequate mental and physical workload (Bohgard, et al., 2009).

The criterion for optimizing a MH system is to lower the costs it generates, where low material flow costs can be achieved by keeping the number of movements and their length at a minimum (Aiello, et al., 2002). Öjmertz (1998) lists different approaches to achieve an efficient materials handling system; if an activity is necessary or can be eliminated, if activities can be combined, if the sequence of activities can be changed, if activities can be rearranged according to place or person, or if method or equipment used can be improved. Aiello et al. (2002) argues that increasing number of moves and the length material is moved can be assumed to increase the costs of material flow. Öjmertz (1998) argues however that not only the materials handling activities consumes time, the idle time between the activities can be the most time consuming. There are different approaches to find the optimal solution of facility layout and material handling system (Aiello, et al., 2002; Hassan, 2010; Sukhota & Peters, 2012). Before performing an optimization, current state must be stated, what and where improvements are needed. The problem can, however, be that data required is stored in different places and in different systems. The collection of all data needed can therefore be time consuming (Denkena, et al., 2014).

2.3 Lean manufacturing

Lean manufacturing, with its roots in Japan, is a term referring to continuously trying to reduce and eliminate waste for a smoother flow (Chen, et al., 2010; Seth & Gupta, 2005). Lean manufacturing is a manufacturing concept and a tool commonly used for continuous improvements of processes that can increase the productivity (Green, et al., 2010) and implementing lean manufacturing can be a competitive advantage (Chen, et al., 2010). Green et al. (2010) state the fundamental of lean manufacturing to reduce and eliminate waste from production processes, where aspects of ergonomics and safety also are considered. Identifying and removing waste and working with continuous improvements can increase the quality and productivity as well as enabling the company to be more cost effective (Chen, et al., 2010). The aim of eliminating waste applies to both short and long-term goals (Green, et al., 2010).

Operations can be classified into three categories, non-value adding (NVA), necessary but non-value adding (NNVA) and value adding (VA) (Hines & Rich, 1997; Seth & Gupta, 2005). Hines and Rich (1997) state that NVA should be eliminated as being pure waste, such

as waiting time not producing a product or service, or handling material more times than necessary. Waste is NVA as it adds no value (Seth & Gupta, 2005). Activities classified as waste are activities which customers are not willing to pay for (Chen, et al., 2010). Such activities can be reduced in areas such as inventory, time to market, space utilized, and amount of human effort needed (Seth & Gupta, 2005). Minimizing waste can, according to Seth and Gupta (2005), lead to underlying problems to the different types of waste coming up to the surface, such as poor management and poor design of processes or operations. This can in turn increase the productivity and enable further reduction of waste. According to Hines and Rich (1997) NNVA can be a waste, however being necessary due to the layout of production, for example where it can be necessary to walk a long distance to collect and deliver parts between operations. NNVA can be reduced by performing a more comprehensive change, such as changing the design of the layout. VA are activities involving processing or conversion of a product, such as turning, which adds value to the product (Hines & Rich, 1997).

Lean manufacturing has the aim of minimizing waste and activities that do not add any value (Domingo, et al., 2007). One strategy to increase the value-adding time can be to increase the number of working hours (Chen, et al., 2010). Chen et al. (2010) argues however that this strategy does not only increase the value-adding time, both time spent on NVA and NNVA will also increase. An appropriate strategy would instead be to cut of NVA and NNVA to increase the amount and proportion of VA (Chen, et al., 2010). When reducing and eliminating waste (*Muda* in Japanese), it is possible to achieve a flow that is even and synchronous (Harrison, et al., 2014). Seven different types of waste can be identified, such as (Domingo, et al., 2007; Harrison, et al., 2014; Hines & Rich, 1997):

- The waste of overproduction - Producing more than necessary is one of the most critical types of wastes as it can lead to bad quality, lower productivity, increase lead time and inventory.
- Waiting - Waiting occurs when time is being used ineffectively; time is wasted.
- Transporting - Waste during transport of material when moved unnecessary distance or handling.
- Inappropriate processing - Occurs when more complex processes than necessary are used.
- Unnecessary inventory - Storage of high inventory can hide problems which cannot be solved or handled without reducing the inventory level.
- Unnecessary motions - Workers could be harmed by unnecessary and excessive motions such as bending and stretching while handling material, which may lower the productivity and even lead to quality problems.
- Defects - Products not meeting customer demands are defect.

According to Liker (2004) there is an eighth type of waste; the waste of human creativity. Not considering workers creativity and ideas, which could help to remove other types of wastes, is seen as a waste (Liker, 2004).

According to Green et al. (2010) a functional lean manufacturing in a company gives positive impact on the material handling. In lean manufacturing, waste and non-value adding processes are reduced in favour of value adding processes (Harrison, et al., 2014). The composition of work is reshaped; time spent on NVA and NNVA is instead spent on VA (Chen, et al., 2010). Green et al. (2010) argue that there is no specific methodology for lean manufacturing concerning material handling. However, they raise these important questions to consider when improving material handling:

- What does the solution need to provide?
- What waste is to be reduced?
- How will the process be affected?
- What metrics should be used to evaluate the results? (Green, et al., 2010, p. 2977)

For companies to become lean they need to adapt, align and implement different concepts and anchor them in the company (Seth & Gupta, 2005). Harrison et al. (2014) describe the process of adapting the lean concept where the first step is to examine the process. When examined, the aim is to identify the amount and type of wastes in the process and to find the root causes as to why wastes occur. The final step is to create and implement solutions to eliminate the wastes, and this process usually includes some technique of process mapping (Harrison, et al., 2014). Value Stream Mapping (VSM) is one suitable tool for waste identification (Domingo, et al., 2007). Other lean tools are Poka Yoke, standardized work, Kaizen and workplace organisation (Seth & Gupta, 2005).

2.4 Value Stream Mapping (VSM)

A value stream includes the activities that add value to the product or service produced (Chen, et al., 2010; Hines & Rich, 1997) a customer demands. In a value stream, activities can be performed in a sequence and parallel (Martin & Osterling, 2014). Both material and information flow are parts of a value stream (Chen, et al., 2010; Martin & Osterling, 2014). Hines and Rich (1997) state the value of identifying wastes in a process and the value stream to, if not remove at least, reduce it. Removal of waste can be seen as a competitive advantage. Reduction of waste creates smooth operations, which in turn can help identify more wastes to make the processes smoother (Hines & Rich, 1997). However, before analysing a value stream the scope must be identified; where the value stream begins and ends (Martin & Osterling, 2014). A suitable tool to use in lean for identifying wastes is Value Stream Mapping (VSM) (Domingo, et al., 2007).

VSM is a tool which helps companies to identify and understand the flow of material and information involved in products' production processes (Rother & Shook, 1999).

Flowcharting material flow, steps and activities involved in a process are elements of VSM, where non-value adding elements can be identified (Ramesh, et al., 2008). VSM is used both for mapping the current state and the future state with the ideal “map” of material and information flow (Chen, et al., 2010). Information flow, work flow and a time line are three key components of a value stream map (Martin & Osterling, 2014). Ramesh et al. (2008) state that the goals of VSM are to identify, reveal and reduce the amount of waste in a process. Activities not adding any value to the final product are considered as waste and should therefore be reduced (Ramesh, et al., 2008). After identifying NVA activities, the next step is to find solutions to reduce them (Chen, et al., 2010). VSM is a tool used for communication, change management (Ramesh, et al., 2008; Rother & Shook, 1999) and strategic planning. It can help companies to identify waste, why and where it occurs (Ramesh, et al., 2008) and to visualize work systems and flow (Martin & Osterling, 2014). Martin and Osterling (2014) argue that VSM is more than just a tool as it offers a holistic view of the work flow through entire systems. The holistic view is critical in order to avoid sub-optimizations with increased costs or lower profit for other sub-processes (Martin & Osterling, 2014).

Rother and Shook (1999), and Martin and Osterling (2014) list advantages of using VSM. According to Rother and Shook (1999) it does not only help companies to identify waste, but also the type of wastes that occur in the value stream. Categorisation of losses and wastes enables the analysis of which type of waste has largest impact on the efficiency (Mathisson-Öjmertz, 1998b). Through categorisations can, according to Mathisson-Öjmertz (1998b), decisions of where and what to change to improve the flow and materials handling easier be made. The creation of a common picture for top management, managers and operators to understand the system studied is another advantage (Martin & Osterling, 2014). Other essential parts of VSM are the linkage of material flow and information flow, and the mapping of a flow from start till end. VSM visualizes the flow and wastes (Rother & Shook, 1999) and therefore enable companies to improve the workflow and lead time by identifying and reducing wastes (Ramesh, et al., 2008). Spaghetti chart is a useful tool in VSM where movements are shown (Chiarini, 2013). According to Chiarini (2013) it visualizes the distance and number of movements, for instance of an employee or a product. However, even though VSM has many benefits, it is not as useful if improvements are not performed on micro levels, if no metrics are used or if there is no action to perform a future state (Martin & Osterling, 2014).

Hines and Rich (1997) present seven tools for VSM, the different tools are presented as VSM tools for a supply chain. However, the tool “process activity mapping” can be applied in one company where it is useful for mapping transport and unnecessary motion. “Process activity mapping” is a suitable method to identify waste and inconsistencies from a workplace, and it consists of five steps (Hines & Rich, 1997):

1. The study of the flow of processes
2. The identification of waste
3. A consideration of whether the process can be rearranged in a more efficient sequence;

4. A consideration of a better flow pattern, involving different flow layout or transport routing; and
5. A consideration of whether everything that is being done at each stage is necessary and what would happen if superfluous tasks were removed.

When designing the future state there are three aspects to consider (Martin & Osterling, 2014). Martin and Osterling (2014) state the first aspect to determine what work should be performed and then removing activities and steps being NVA. Afterwards making work flow and as last aspect managing the work for continuous improvements (Martin & Osterling, 2014).

2.5 Summary of theory

Companies are constantly aiming for improvements, being cost efficient and meeting customers' expectations (Mathisson-Öjmertz, 1998b). The expenses of the material flow are assumed to be related to the number of times materials are moved, and the distance; increased movement leads to increased expenses (Aiello, et al., 2002). Therefore, high utilization of the facility layout, with a suitable MH system in relation to the location of machines and production units is advocated (Drira, et al., 2007).

Activities in a process can be identified by Lean Manufacturing and the tool VSM (Ramesh, et al., 2008). Afterwards they can be classified into three categories, non-value adding (NVA), necessary but non-value adding (NNVA) and value adding (VA) (Hines & Rich, 1997; Seth & Gupta, 2005), where NVA activities are waste. Waste, in terms of transportation, unnecessary motions, waiting (Domingo, et al., 2007; Harrison, et al., 2014; Hines & Rich, 1997) and the waste of human creativity (Liker, 2004) should be reduced or eliminated. NNVA can be reduced by performing a more comprehensive change, such as changing the design of the layout (Hines & Rich, 1997). In VSM, Spaghetti chart is a useful tool to map movements (Chiarini, 2013) and "Process activity mapping" is a suitable method to follow to identify, reduce and eliminate waste in a process (Hines & Rich, 1997):

1. The study of the flow of processes
2. The identification of waste
3. A consideration of whether the process can be rearranged in a more efficient sequence;
4. A consideration of a better flow pattern, involving different flow layout or transport routing; and
5. A consideration of whether everything that is being done at each stage is necessary and what would happen if superfluous tasks were removed.

Storing enough material close to the operations will lower storage and shorter the movement of material (Domingo, et al., 2007). Therefore, finding another location of work in progress at the case company can help to improve the movement of material from storage to production areas. The material handling can be improved by either better utilization of the current system

or reducing number of necessary steps such as using forklifts, automated handling equipment and lifting aids for manual handling (Öjmertz, 1998). Having the necessary amount of forklifts needed, investing in automated handling equipment such as robots picking from and placing on pallets could therefore improve the material handling at the case company, and at the same time facilitate the movement of material with one forklift available for each pallet required.

Öjmertz (1998) lists different approaches to achieve an efficient materials handling system; if an activity is necessary or can be eliminated, if activities can be combined, if the sequence of activities can be changed, if activities can be rearranged according to place or person, or if method or equipment used can be improved. Classification of activities as NVA, NNVA and VA can help determine which activities are necessary or can be eliminated (Seth & Gupta, 2005). Combining or changing sequence of activities might support and improve the material handling at the case company, as well as if the activity can be performed at another location or by another person.

When designing facility layout, consideration has to be taken to the MH system (Aiello, et al., 2002; Sukhota & Peters, 2012). Therefore, whether a change in the layout of the production area can result in improved flow and handling of material is dependent upon if it works with the current MH system or if it should be re-designed (Aiello, et al., 2002). The same applies in the opposite way.

3 Method and implementation

This chapter consists of the methods used to conduct the research, the techniques applied, the types of data that has been collected and the research process.

3.1 Research design

This section comprises the methodological approach for the thesis. The research approach is deductive (Bryman, 2016) and is characterised as interpretivism, as trying to investigate a problem in its natural setting. Inductive reasoning style is applied where hypothesis is generated from the study conducted (Williamson, 2002).

3.1.1 Case study

The research method used in this thesis is a case study design. Case study research is a relevant method to use to create “an understanding of social phenomena in their natural setting” (Williamson, 2002, p. 111). Data collection techniques can be either or both qualitative and quantitative, usually with the primary aim to collect qualitative data. Qualitative data was the primary data collection method for this case. A strength of using case study is its context specific approach where specific phenomenon can be studied (Williamson, 2002). However, a negative aspect of case study is that it can be time-consuming to conduct, both the collection of qualitative and quantitative data as well as the analysis of it (Williamson, 2002).

The case study research was based on one case company; LEAX. The case study was conducted at the company’s facility in Falköping where the material flow and production layout were investigated. The material flow was analysed between storage and production area, and the way the material is handled in production section A. Furthermore, the production layout was studied concerning its impact upon the material flow and handling.

The choice of case study design was based on its appropriateness for studying one specific case, with the possibility of in depth information gathering and trying to solve one specific problem. The problem identified at the case company can, however, be related to other companies operating in similar markets and structured ways of working in a production process.

3.1.2 Data collection techniques

The selection of data collection techniques was based on the case study design and the case company. Multiple techniques were used to increase the validity of the research by triangulation (Cohen, et al., 2011). Cohen et.al (2011) describes the advantage of triangulation where strengths and weaknesses can offset each other from different methods. Relevant sources of data in case study research are documents, interviews and observations (Cohen, et al., 2011), therefore these techniques were chosen for this research. Sources of data were information and documentation from the company, on top of qualitative data collected during

study. Qualitative data is relevant for the analysis of material flow, handling of material and the layout of production.

Document analysis

The reason for documents analysis was to gain information about the case company. Relevant documents covered flow of material from storage to production area, layout of the production area and VSM. Documents used were organisation chart, shift scheduling, production layout and process flow charts. Analysis of these documents provided a base to perform the VSM, which afterwards was analysed.

Observations

Advantages of observations are the collection of non-verbal behaviour, the possibility to study ongoing behaviour in its original context (Cohen, et al., 2011). To perform VSM for article B's production process, observations of the production process as well as its surrounding activities were performed. The operators were observed, how they moved and handled the material, what they were doing before, during and after an operation and other activities involved in their daily work. Observations were conducted during the morning shifts on weekdays. Before performing observations, operators were informed regarding the purpose of the observations and that the activities performed during the production process were of interest, and consent was obtained. Cohen et al. (2011) argue that observation is a powerful data collection technique, however the risk of biases must be considered. In respect with the subjective selection the researcher might have, additional techniques to collect data should be used to triangulate the results (Cohen, et al., 2011). Therefore, interviews were conducted with the operators who were observed.

Interviews

During observations, unstructured interviews were held with operators when necessary to understand why some types of activities were performed and why they were performed in such ways. Semi-structured interviews were conducted after observations. The advantage of performing semi-structured interviews was that the operators' feedback and input about the current flow of material and design of layout could be recognized (Matthews & Ross, 2010). By interviewing, more in-depth information and the operators' perspectives were obtained (Williamson, 2002). Semi-structured interview questions were used with room for discussion and follow-up questions (see Appendix B for interview questions).

Semi-structured interview was also conducted with a production engineer regarding the ideas and thoughts concerning how to solve the identified problems in production section A. Discussions, in terms of unstructured interviews, were held with the production manager, logistics manager and production planner as and when necessary. Williamson (2002) states the usefulness of unstructured interviews conducted in beforehand to explore a subject. An overview of respondents at case company is shown in table 1.

Table 1: Overview of respondents interviewed at case company (n=number of respondents)

Data collection tool	Respondents LEAX
Semi-structured interviews	n = 5
Unstructured interviews	n = 7

3.2 Research process

The process began end of November 2017 when contact was established with LEAX Skaraborg AB. The thesis study was carried out between January and May 2018. In the beginning of the study, documents of the company and general information about the company were studied. Afterwards a tour of the factory and discussions with the production and logistics manager were carried out. Next step was a comprehensive literature study of mainly material flow and handling, Lean and the tool VSM. VSM was conducted twice; first of the current state, and after the analysis with suggested improvements a future state could be established. During the whole process, data collection and literature study was carried out in parallel. Discussions were held, when needed, with the production manager and production planner to gain detailed information. The access and availability of an office space at LEAX during the research process enabled contact with managers and operators as and when needed.

3.2.1 Literature overview

Based on the purpose of the thesis and research questions, related literature was selected. Main sources of literature were books and journal articles. Access to articles was gained from Jönköping University database Primo and Google Scholar. Keywords used were: *facility layout, material handling, manual material handling, material flow, lean manufacturing, VSM*.

3.2.2 Study at case company

The study at LEAX began early February 2018, where discussion was held with the production manager concerning the problem description and research questions. Afterwards discussions were held with selected managers when needed, as well as operators before data collection for VSM. It is, according to Lasa et.al (2008), important to plan in detail how the VSM will be performed in order to get as good results as possible. Therefore, establishing an overview of the process flows was important. Observations were performed prior to collecting data to establish an overview of the processes and data collection. Next step was discussion with the production planner regarding the shift scheduling to plan the study of production section A and the process flow of article B.

The current flow and handling of material were mapped with VSM to identify the NVA, NNVA and VA activities. The mapping was conducted on one high volume article which was produced and delivered weekly to customer. The data collection process was based on discussions with the production planner regarding operation time and flow of the chosen

article. The mapping was conducted on one specific batch consisting of 96 items, from start to end of production, which was labelled for identification and traceability. The choice of the specific batch was made to ensure reliable results of the movement and handling of the material throughout the flow. Following one batch of product enabled data collection of all activities where material was handled and moved before, during and after all operations. Such activities could be overlooked if different batches were studied.

During observations, times, movements and motions were measured. Notes were taken during observations and transcribed afterwards. Since the amount of information forgotten increases as time passes it is, according to Cohen et al. (2011), important to transcribe as soon as possible. Risk of biases in observations must be considered, such as the selective attention of the observer, selective data entry and memory, and how the participants react to being observed, for example working harder or different compared to what they normally do (Cohen, et al., 2011). Interviews were recorded upon obtaining permission from interviewees. Recording enables structured analysis of interview data, to draw conclusions, and lowers the risk of missing details while taking notes (Williamson, 2002). All recorded interviews were transcribed, as stated by Cohen et al. (2011) it is an important step to perform. The transcriptions were read several times to ensure no important data was missed. The respondents of interviews conducted are listed in table 2.

Table 2: Overview of respondents of interviews conducted

Role	Unstructured interview	Semi-structured interview
Production manager	1	0
Logistics manager	1	0
Production planner	1	0
Production engineer	0	1
Operator	4	4

3.2.3 Data analysis

Analysing qualitative data involves organising and making sense of the data. The data analysis is dependent upon *fitness for purpose* (Cohen, et al., 2011). According to Cohen et al. (2011), fitness for purpose is achieved when the analysis is conducted in correlation with the purpose of the research and methods used for data collection. The data analysis was organised into three steps, where the first was to analyse the VSM conducted. The analysis of the data collected during observations was conducted in two ways. All data collected were structured in an Excel spreadsheet where total time, movements and motions were calculated. VSM and process activity mapping were used for further analysis. The next step was to analyse the data collected during semi-structured interviews. The interview transcriptions were read though several times in order to, as stated by Cohen et al. (2011), understand the context and meaning as a whole. The semi-structured interview data was analysed according to what was said, both in comparison between employees and in relation to the VSM. As mentioned by Cohen et al.

(2011), data analysis can be used to compare answers given in interviews with behaviours observed.

The third step of the data analysis was to remove and reduce activities labelled as NVA and NNVA to improve the material flow and handling throughout the production process. The analysis generated suggestions for improvements of material movement, material flow and a suggestion for new design for production layout.

Confidentiality was assured to all respondents to encourage honest cooperation from respondents. Ethical principles were considered when employees were informed of the research, and that the observations were not of personal behaviours, instead observations of the production processes (Cohen, et al., 2011).

3.3 Reliability and validity

Trustworthiness of the study is portrayed through the reliability and validity of the research process. Reliability is concerned with dependability, replicability over time, precision, accuracy and consistency of the research conducted. With other words if the same study would be conducted in a similar setting, similar results would be generated (Cohen, et al., 2011). Therefore, the methodological approach is described in Chapter 3.

The validity of the research is dependent upon the relevance of the data collected and therefore determines the quality of the research (Matthews & Ross, 2010). Matthews and Ross (2010) argue that triangulation of methods is a strategy to increase the validity. Therefore, both observations and interviews were chosen as data collection techniques, as they also are considered relevant for this study. Cohen et al. (2011) also state that credibility and reliability are achieved by diverse data pointing at the same evidence. Threats to the validity of the research include the behaviour of the researcher and the interpretation of data collected of the phenomenon studied (Cohen, et al., 2011; Williamson, 2002). Actions have been taken to increase the internal validity, such as carefully going through recordings and transcripts several times to reduce risks of misunderstandings and misinterpretations. The generalisability of this study applies to companies operating in similar environments.

4 Findings and analysis

In this chapter, findings and analysis from the study conducted at LEAX are presented following the “process activity mapping” tool for VSM by Hines and Rich (1997). Thereon are suggestions for improvements of movements and handling of materials presented.

4.1 The study of process flow

The production process of article B consists of five operations, see figure 1. OP10 is the first operation consisting of turning machines. At OP20 article B is hardened followed by broaching at OP30. OP40 is surface treatment, which is performed by a supplier. The last operation is OP50 where article B is ground and cleaned. Raw materials and semi-finished products from supplier are moved and placed at the bottom left corner of production section A by a forklift driver. Finished products are picked up by a forklift driver from the same spot. All movements of material during the production process are shown in figure 1.

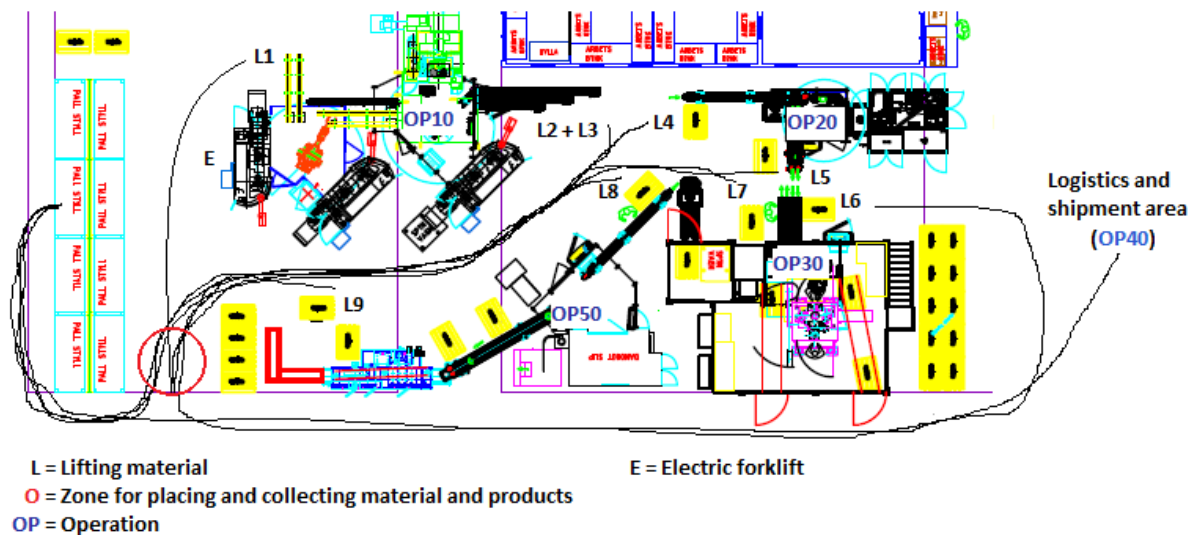


Figure 1: Spaghetti chart for movements of material

Some years ago, the operations in production section A were manually loaded and unloaded. The current layout of section A is semi-automated. All operations are automated with manual activities performed in between lifting on and off conveyor belts. The work environment is more stressful now than before due to operators running several machines simultaneously. It is the same amount of MMH activities now as when the operators manually loaded the machines; as to say, a not very effective semi-automation. Earlier there were only two operators in section A. Now there are three, due to the time and effort required to move and handle the material, especially the manual handling. However, for section A to be efficient there should only be two operators.

During the production process of article B, one product is handled and lifted in total nine times. However, including all measurements of first piece, last piece and pieces in a pre-set

interval entails even more material lifting. Article B was chosen for the VSM due to its high volume in manufacturing and therefore, high flow of material. The current state of the movement and handling of material is shown in Appendix C with the activities during the production process and in appendix D with a VSM of the material flow. The focus is on the time spent on material handling and movement between operations.

OP10

Before producing a new order, a new pallet is placed after OP10. A pallet with raw material is moved, from zone O in figure 1 or from pallet rack, and placed in front of OP10, except if the same type of product was produced previously. The old pallet with raw material is moved and placed in the pallet rack with electric forklift. If empty, it is either moved to the last operation where it is used for finished products or taken apart and placed in the pallet rack.

When starting a new order, the first part produced is inspected in a measuring machine whether it fits into set requirements. If not according to requirements, changes in the set-up of the machine are performed followed by inspection of the next part produced. When the measurements are approved the production can start. Material is manually handled when lifted from pallet to conveyor belt (L1), (figure 1). The raw material is not sorted in any order on the pallet. This motion involves lifting and turning of material with a weight of six kilos per item. On average four parts are lifted every time and for a pallet of 96 parts, four and a half minutes are spent. The operation is automated and afterwards material is lifted from conveyor belt to measuring table and then placed on pallet. One part is inspected for all measures, in total lifting and rotating the part seven times. The rest of the parts are inspected for one measurement and therefore lifted twice (L2 + L3). To be able to reach, the materials must be pushed forward on the conveyor belt. Before picked up they are dried using a blower. On average, pushing forward, blow drying, lifting, measuring and placing materials takes 78 seconds of which 45 seconds is spent handling material. In total almost 35 minutes are spent on those activities for one pallet of 96 pieces with a production time of 7 hours and 52 minutes. During the whole operation the operator is lifting 423 times. Lifting is also performed while changing insert and at first piece inspection. When the pallet is finished at OP10 it is either placed directly by OP20 or moved and placed in the pallet rack, the latter more common.

OP20

The pallet is taken and moved from pallet rack with electric forklift and placed in front of OP20. Materials are manually handled, taken from pallet, cleaned with a towel and placed on a conveyor belt (L4). Afterwards, one of the two operators also performs the drying process. The operation is automated and when products are finished they are, by a robot, placed on two conveyor belts. The operators then manually take the materials and place them on a pallet after the operation (L5). On average six products are lifted on and off the conveyor belt each time and for the whole pallet over 16 minutes are spent on handling the material. In relation to the production time, this entails 15 % of the production time spent on MMH with a total of

192 times lifting material. The percentage MMH out of production times are listed for all operations in table 3. After OP20 the pallet is again moved by electric forklift and placed on pallet rack.

OP30

The pallet is taken from pallet rack with electric forklift and placed by OP30. Due to the limited amount of space between the operations in section A, the pallet is moved around the flow by the truck aisle. The previous pallet is moved by forklift and the pallet with article B is then placed by OP30 by forklift. When producing a new batch, the first part produced is always inspected, then approximately every 20th part is inspected in a measuring machine. During the production, except the first piece inspection, five parts are inspected which takes long time and the operator needs to handle the material and move a distance with it.

Material is manually handled as it is lifted from pallet to conveyor belt (L6) and from conveyor belt to pallet (L7). 13 minutes is spent on lifting on and off material, which is 10 % of the production time. Beyond this, time is also spent lifting and moving material during inspections. After OP30 the pallet is moved by electric forklift to the logistics and shipment area where the pallet is packed and shipped for transport to supplier for the external operation. The location is just to the right of section A. The pallet is, however, located to the left of OP30. It is therefore moved all the way around the production area due to the limited space between the operations.

OP40

The pallet is shipped to a supplier for surface treatment. When it arrives back at LEAX, the pallet is checked in and then moved by the electric forklift driver and placed in the zone for placing and collecting material and products in section A.

OP50

The pallet is moved and placed at the start of OP50 with an electric forklift. If the previous order is a different article, set-up time is needed. During set-up, settings and tools are changed in the machine. Afterwards a first piece inspection is performed before the actual production starts. Material is manually lifted from pallet and placed on conveyor belt (L8). OP50 consists of two operation, however connected with a conveyor belt and therefore considered as one.

The pallet dedicated for finished products is moved 4 metres and placed right after OP50. Due to the insufficient number of forklifts, sometimes the pallets are placed on the floor. This results in bad ergonomic posture while lifting material off conveyor belt and placing it on the pallet (L9). This is due to another article being cleaned at the same time and there is only one available forklift.

Findings and analysis

The MMH activities before and after OP50 consume 14 minutes with a total of 192 times lifting. Activities that also consume time and increase the movement are collecting material for pallets from pallet rack and putting away used material such as plastics, paper and paperboard. During production in OP50 there is inspection of first piece, last piece and every 30th piece. For first and last piece measurements are inspected on a measuring table and in a measuring machine. For every 30th piece measurements are inspected on a measuring table. Those measurements entail lifting and rotating the part four to five times more and increased movement for the operators.

Table 3: Time spent on material handling in relation to production time

	OP10	OP20	OP30	OP50	Total
Number of times lifting	423	192	192	192	999
Time spent on handling material (min)	39.10	16.38	13.07	14.41	82.96
Production time (min)	472.00	106.73	133.75	232.98	945.46
Time spent on handling material in relation to production time	8 %	15 %	10 %	6 %	9 %

4.2 The identification of waste

Classification of activities according to NVA, NNVA and VA are shown in the process activity mapping in appendix C. In relation to the movement and handling of material, the following types of wastes have been identified in the production of article B.

Transportation

Movements of material are activities classified as NVA and NNVA, except for the first and last transportations, for which distances moved are NNVA. Moving material between storage and production areas and between operations is necessary for the production process to be able to run smoothly. However, not all movements and associated distances are necessary and therefore, classified as NVA. NVA include transportation over longer distance than necessary, such as transporting material to and from the pallet rack between OP10, OP20 and OP30 when operations are located next to one another. After OP30, the pallet is moved, instead of just 8 metres, all the way around the production area due to limited space in that location of the shop floor. This movement, a total of 44 metres, is considered a waste because it is unnecessary.

Unnecessary motions

The MMH came up to 999 times of lifting, in total consuming 83 minutes during the production of article B. Lifting material between pallet and conveyor belt does not create any value for the customer and is therefore seen as a waste. However, the current design makes the MMH necessary, and is therefore also classified as NNVA. Unnecessary and excessive motions such as bending and stretching while handling material can lead to injuries, which

may lower the productivity and even lead to quality problems. In section A the most of the forklifts performs the lifting operation, however not all of them. This requires unnecessary motions, raising the forklift takes time and has physical impact on the operators. The number of forklifts available in section A and the number of forklifts needed, one per pallet before and after each operation, do not match. There is a shortage of two forklifts which entails more lifting and moving material. When an operator wants to move a pallet, he/she needs to use the electric forklift or borrow a forklift currently holding another pallet. The pallet from the borrowed forklift must be moved before usage, and then be returned to its original position.

The shortage of forklifts also causes unnecessary motions at OP50 when two different articles are produced at the same time. Therefore, two different pallets are needed after OP50. However, after OP50 there is only one forklift available which results in the pallet for article B being handled several times. This entails unnecessary motions and movements as the operator needs to bend to place finished parts on the pallet when it is placed on the floor.

Waiting

The operators are currently performing the maximum amount of lifting that they are allowed per shift. Therefore, they are not allowed to help others even when available. Time is used ineffectively when not performing any value-added activities.

The waste of human creativity

Large amount of time is spent on MMH and unnecessary transportations. Lifting materials between pallets and conveyor belts does not require any creativity from the operators. However, operators' creativity for ideas regarding, for instance improvements, could be utilized in greater extent if less time was spent on NVA and NNVA activities.

4.3 Analysis of process flow

The change from manual to semi-automated production did not result in any improvements of the material handling. Walking back and forth between operations, moving and handling material is time consuming and physically challenging. The work tasks are less monotone today, but more stressful with high demands performing several activities simultaneously. Another impact factor is the uneven workload for the operators. If the machines are running as normal the operators have the time to move and handle material. However, when a machine is stopped for break or set-up, the workload becomes intense and at times high.

Step 1 in the process flow of article B, as shown in appendix C, is NNVA activity since the distance of moving the material is necessary. The first MMH (L1) is difficult to improve as the raw material is placed higgledy-piggledy on the pallet and therefore difficult for a robot to handle. For robot handling, the material must be sorted in rows and lines on the pallet for pick-up. This entails a discussion with the supplier whether it would be possible to sort the raw material, if costs would increase and if the same amount of material would fit on the

Findings and analysis

pallet. The reason to remove L1 is that it is the heaviest lifting; weighting at six kilos of raw material. Some other articles are even heavier than article B. Regarding the number of times lifting, L2 and L3 should be reduced or removed. Materials are lifted 327 times, taking almost 35 minutes. Investing in automated blow dryer on the conveyor belt and a vision camera inspecting the parts produced would reduce time spent and number of lifting needed. Material would only be lifted 96 times, from conveyor belt to pallet, and the time spent could be reduced by 50 %. The reason for inspection of all parts is due to unreliable production process. The best solution would be to remove the root cause of the problems; removing the need for inspection. However, as it is now some type of automated inspection would be preferred.

It is easier for a robot to place on pallet than pick from pallet, since placing on pallet does not require any vision system of the robot and is therefore cheaper to invest in. After OP10 it might be difficult to have space for three pallets (as desired since three different articles can be produced at the same time). However, if the robot is to place directly onto the pallets, the MMH activity in step 4 will be removed. Distance moved in steps 5, 7, 11 and 13 could be greatly reduced if article B is produced in OP10, OP20 and OP30 simultaneously. In that case, the pallets would have to be moved 5 metres instead of the current 128.5 metres. The amount of storage between operations could also be reduced. This requires changes in the production planning and scheduling of different articles to synchronise the flow.

There are some easy-to-solve problems that should be taken care of right away. For instance, sometimes after OP20 materials are manually handled from conveyor belt to pallet (L5), the pallet is moved straight to OP30 and materials are manually handled from pallet to conveyor belt (L6). Instead material could be handled only once by moving from conveyor belt to conveyor belt. This will eliminate one MMH activity and one pallet usage, and eliminate the movement of material in steps 11 and 13. This change requires production of the same type of article in both operations. The next step to further improve the material movement and handling would be to connect the conveyor belts, where no MMH or movement would be necessary. This would eliminate L5 and L6 and reduce the distance of material movement by 71 metres.

The layout in section A is designed to flow, however, most of the articles produced are shipped to a supplier after OP30. The logistics and shipment area is located next to OP30. Therefore, unnecessary movements are created before and after OP30. Before the pallet is moved all the way around section A, and after it is moved through section A and all the way around. Therefore, changing location of conveyor belts going in and out of OP30 will result in change of locations for L6 and L7. The distance in step 17 would be reduced to 5 metres. Simultaneously, time will be saved since the operator can use the forklift at the location and does not need to use the electric forklift located on the opposite side of section A.

By investing in a robot with vision system, picking from pallet at OP50 the MMH in step 20 (L8) can be eliminated. If building a return conveyor belt, it might also be possible for the robot to place on pallet, eliminating L9. The question is, however, if it is possible to have a return conveyor belt without interrupting the work of other operators or causing transport issues through the production area. A solution could be if the location of OP50 is moved to the left, then an aisle could be created between OP30 and OP50. The location of OP50 can be altered, however, the only concern is that the same operator is used for OP20 and OP30.

4.3.1 Re-evaluation for a better process sequence

A rearrangement that could save both time and movement would be to change the locations of the conveyor belts to and from OP30. This change entails change of pallet locations before and after OP30, see figure 2. The movement of material between storage and production area will be shortened.

Packing materials are stored on the right side of the pallet rack. However, other pallets are stored there with materials which are not frequently used, such as spare parts for machines. In order to improve the material flow, the less used pallets should be stored on the left and work in progress pallets on the right. The result of storing work in progress closer to the operations is reduced distance as shown in figure 2. However, the packaging material is stored in such a way that makes material handling at a higher level of the pallet rack difficult. There is one pallet in the bottom layer that hinders the electric forklift from operating. A solution could be to place two pallets underneath and place the packing material on top of it.

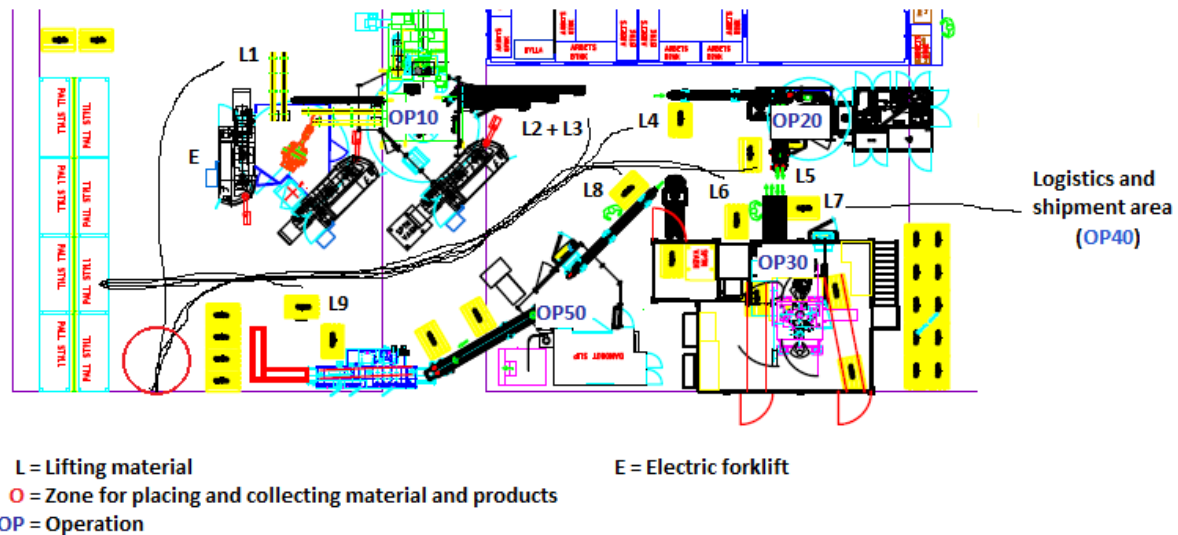


Figure 2: Change of process sequence for improved movements of material

4.3.2 Re-evaluation for a better flow pattern, layout and transport routing

Often a low number of materials, on average four or five, are lifted on and off the conveyor belts each time at various operations. This entails unnecessary movements since the operators are moving to and from the pallet rack and machines numerous times during a shift.

Therefore, handling more materials at the same time at each operation, lifting on and off a larger quantity (one by one) will reduce the movement. The number of times a material is handled will not change, however movements can be eliminated.

The material is, almost every time, after OP10 and OP20, moved and placed in the pallet rack located to the left of section A and then picked up before OP20, OP30 and sometimes OP50 (after the external operation). The path taken is not optimal. In general, the area in section A is quite narrow and does not facilitate a suitable way of handling and moving material. There are many pallets located at the various operations, which limit the free space. Operating the electric forklift is quite tricky in avoiding contact with machines, pallets or operators. The distance could be reduced by a change of layout and the path could be re-designed. The suggested change of layout is shown in figure 3. Work in progress could be stored in the mobile pallet rack. The proposed change of layout could lower the distance and time of movement. The change of layout could also ease the movement, since the path would be a straight line with ample space for both material movement and usage of forklift. However, consideration should be taken regarding the mobile pallet rack at times not functioning as intended and therefore forcing operators to manage it by themselves. The mobile pallet rack is at times out of order due to its unreliable functioning.

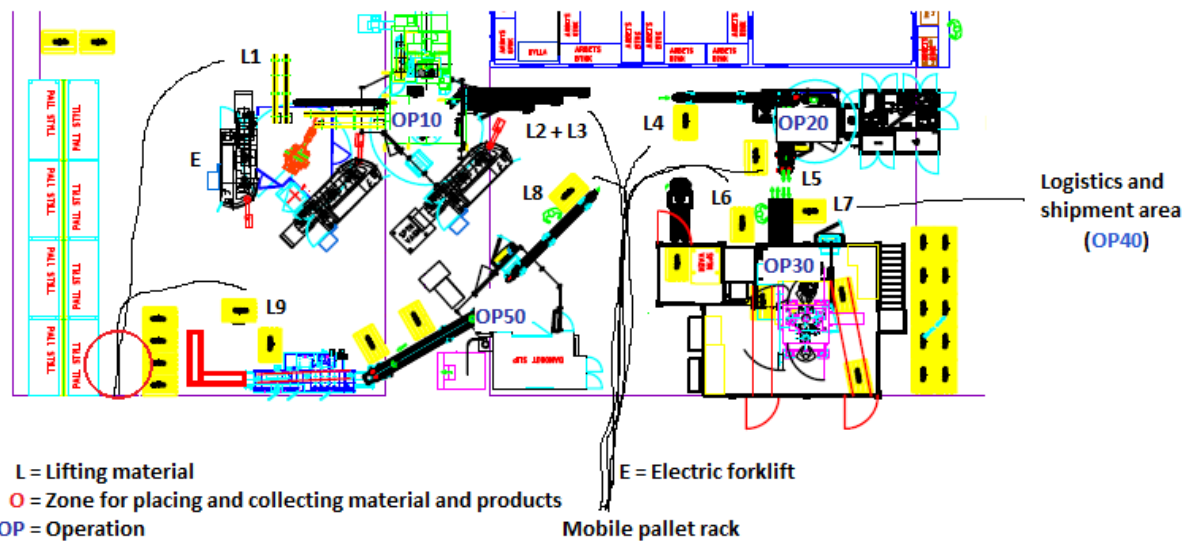


Figure 3: Change in layout for improved material flow

In section A there are large numbers of MMH activities. The amount of lifting is at the maximum limit of what is allowed for the operators. 9 % of the total production time is spent on MMH, counting to 999 times lifting except for inspections of first piece, last piece and pieces in a pre-set interval. The heavy loads, with motions of lifting and turning of materials up to six kilos, can in the long run result in injuries. As it is also time consuming, it is crucial to reduce the number of times material is manually handled and lifted. The reduction of motions will not only reduce time spent on handling material, it will also free up time to be spent on VA activities. The waste of human creativity and waiting time can also be reduced. Therefore, reducing the number of times the material is lifted can enable operators to assist

others when available. The impact of heavy and repetitive motions is also reduced, and the risk of injuries is lowered.

4.3.3 Re-evaluation of activities

The layout design of production section A provides a continuous flow. A continuous flow might, however, not be possible. OP20 produces one product while three different products can be produced simultaneously in OP10. Due to long set-up time in OP20 it might not be suitable to connect it to OP30, even though every article produced in OP20 is also produced in OP30. Between OP20 and OP30 it is useful to have an aisle and therefore have the operations disconnected. However, connecting operations might be possible if the conveyor belt is placed higher up with the possibility to walk underneath.

Due to the limited space in section A, a robot placed in the middle handling the material is not an option. There are many pallets in section A in the narrow space as it is today. Changes such as investing in robots and connecting operations might result in less free space. Although there is discussion against connecting operations with a continuous flow, the advantages should be considered. Fewer and shorter material movements, less MMH activities and fewer pallets needed could be achieved, as shown in figure 4.

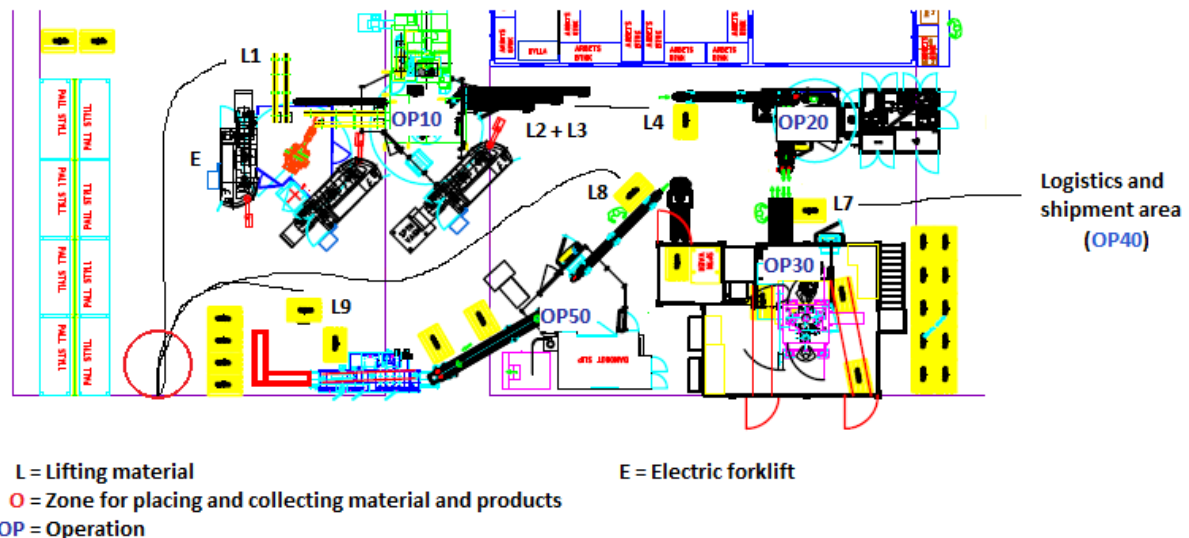


Figure 4: Connecting operations for improved movements of material

4.4 Future state suggestions

One immediate suggestion for improvement is to invest in two more forklifts, especially forklifts performing the lifting operation for different height levels. They will ease the work of the operators while lowering and raising pallets, which is a common activity. There should be one forklift for every pallet before and after each operation in production section A. Having enough forklifts will remove unnecessary motions and movements and therefore save time. Since the operators are already performing maximal lifting, forklifts with electrical aid while performing the lifting operation should be prioritized.

The number of times MMH activities are performed can be reduced by investing in robots. Robots could handle the movement between conveyor belts and pallets before and after each operation. The time spent on MMH activities would be greatly reduced and exposure to injuries will be lowered. However, due to the limited free space in production section A, it may not be suitable for robots. Another suggestion would therefore be to invest in vision systems with cameras for the robots operating the machines. Then each robot at every operation could pick from pallets before and place on pallets after the operation. This suggestion would also remove all MMH. However, it is not as simple at OP30 due to the location of the robot at a higher level and due to oily finished products. Placing them directly onto the pallets would result in pallets being dirty. Another aspect to consider is that investment in automation will not be profitable if the number of operators cannot be minimized in section A.

One system that could reduce the number of times the material is lifted, and support robots picking from and placing on pallets, is use of palettes. Palette is a type of smaller pallet made of metal. The material is placed on the metal, in different layers with distances between the layers. Not only MMH activities can be reduced, also the movement and the number of pallets needed in production section A. Removing some pallets would also free space which in turn would facilitate and ease the movement of material in section A. Appropriate size could be 3*5 parts of article B in four layers, in total 60 parts. The palettes system can be used through the production process without concerning oily and dirty parts. Pallets would then only be necessary for incoming raw material for OP10 and after OP50 for finished products.

4.4.1 List of suggested changes for improvements

Reducing and eliminating the different types of wastes identified in the production process of article B can improve the material flow, the way the material is handled and improve the working conditions for the operators. Future state suggestions can be divided into several steps depending on the scope of change and amount of investment needed. Considerations of the difficulties to implement the suggested changes are also noted. The following suggestions for improvements are derived:

1. Investing in more forklifts, especially with electrical aid while performing the lifting operation
 - Reduction of unnecessary motions
2. Changing location of work in progress and less used pallets on pallet rack
 - Reduction of movement by 40.5 metres
3. Investing in automated blow drying on the conveyor belt and some type of vision camera inspecting the measurements after OP10.
 - Removing L2 and reducing number of times lifted from 327 to 96 times
4. Changing location of conveyor belts going in and out of OP30; change of locations of L6 and L7.
 - Reduction of movement by 51 metres

Findings and analysis

5. Handling material once between OP20 and OP30, moving from conveyor belt to conveyor belt.
 - Reduction of movement by 71 metres, removing L6 and one less pallet is needed
6. Connecting conveyor belts between OP20 and OP30.
 - Reduction of movement by 71 metres and removing L5 and L6
7. Having a robot lifting raw material on conveyor belt before OP10.
 - Removing L1, the heaviest lifting throughout the production process of article B.
8. By vision systems with cameras enable each robot to pick and place on pallets and/or palettes.
 - Reduction of movement by 55 metres and removing L2-L8
9. Changing location of OP50 to create an aisle between OP30 and OP50.
 - Better support of the movement of material in production section A

The process flow and the VSM of the material flow after suggested changes 1-7 are shown in appendix E and F.

5 Discussion

In this chapter, the method is discussed followed by a discussion of findings and analysis in connection to the theory. The implications of the findings are discussed for each research question separately.

5.1 Discussion of method

The chosen method to fulfil the purpose of the research and answer the three research questions was case study. A literature study was carried out in parallel with data collection at the case company. Conducting observations and unstructured interviews with selected managers and the production planner prior to data collection created an overview of the process, which as stated by Lasa et.al (2008) is important. The combination of observations and semi-structured interviews enabled data collection of both actions and movements and at the same time the operators' point of view. The choice of several data collection techniques improved the validity of the data collected.

The data collection during the observations was the most difficult part of the research conducted. Measuring time and distance of movements of one or several operators simultaneously demands high focus to get reliable and trustworthy numbers and results. The observations conducted prior to data collection therefore were important to establish an overview of the process and to be well-prepared for the data collection.

Findings from the literature study together with the findings and analysis of the case study are used to answer the three research questions. The findings from the case study were presented for the case company for evaluation of the study and research conducted. Several of the proposed changes for improvements, as listed in section 4.4.1, were known at the company, but no action had been taken to perform the improvements. Thanks to the data collected of distance of movements, number of times lifting and time spent on MMH with comparison of current and future state, improvements will be implemented. The suggested change of location for conveyor belts at OP30 was, however, not thought of at the case company.

5.2 Discussion of findings and analysis

The purpose of this thesis was to explore options for material flow improvements and handling of material in production area. Ways to improve the material flow and handling in the current layout and whether a change in the layout can further be improved are discussed in each subchapter.

5.2.1 How can the movement of material from storage to production areas be improved? (RQ1)

Material flow can be improved by shortening the distance of movement, reducing the number of lifting, and moving and storing material closer to the operations. Suggestions for ways to

improve the material flow are discussed in chapter 4. The movement of material is challenging in production section A due to the limited space available, which as stated by Domingo et al. (2007) is common in manufacturing companies. The movement of material from storage to production area is affected by the layout of the facility (Aiello, et al., 2002). Machines, tools and materials are located close to each other for efficient use of space, however, this makes the movement of material complicated. The problem is based on the current way the material is moved, which is not properly structured. As described by Mulcahy (1999), unnecessary movements and risk of injuries of employees can be reduced with a proper structure. A proper structure is achieved by identifying, reducing, and removing waste. Activities not adding value characterised as waste should be reduced (Öjmertz, 1998). Therefore, working with lean manufacturing for continuous reduction of waste and improvement of flow is advantageous (Chen, et al., 2010; Seth & Gupta, 2005). Availability of the appropriate type and number of equipment facilitates smooth and efficient material flow. In section A, the shortage of two forklifts causes NVA activities for the operators in performing unnecessary motions. Therefore, investing in necessary equipment will improve the material flow.

Activities classified as NVA are considered as waste and should therefore be eliminated. NNVA activities are, however, necessary due to the layout design (Hines & Rich, 1997). In the production process of article B the distances and number of times materials are moved are both seen as NVA and NNVA activities since some of the activities can be reduced or removed if the layout is re-designed. The first and last movements are NNVA. However, all other movements could be reduced by distance or times moved and are therefore classified as both NVA and NNVA. They are not VA since moving material does not create any value for the product produced.

VSM is a useful tool where the product flow is mapped (Martin & Osterling, 2014). Through categorisations of wastages, according to Mathisson-Öjmertz (1998b), decisions can be made on the changes needed to improve the flow and handling of material. The creation of a common picture for top management, managers and operators to visualise the system is an advantage (Martin & Osterling, 2014). By the suggested changes listed in section 4.4.1, the future state of activities during production process in appendix E and VSM of the material flow in appendix F improvements for material movements are visualised. All employees, from top managers to operators, have access to the same information with a common picture of the current and suggested future state.

5.2.2 In what way can the material handling be improved? (RQ2)

Material handling was considered problematic since operators are repetitively lifting and handling material manually. Findings from the study conducted shows that 9 % of the production time of article B is spent on MMH activities. Handling material is a necessity to ensure the material is moved where and when needed (Mathisson-Öjmertz, 1998b). Öjmertz (1998) argues however that those activities not adding value characterised as waste should be

reduced. Therefore, activities during the production process of article B are characterised as NVA and NNVA. As for the movement of material, handling the material is a necessity but not to the same extent as it is currently performed. 999 times of lifting is a noteworthy number concerning MMH activities.

Improvements of the material handling can be achieved by either improving the current system or reducing the number of necessary steps (Öjmertz, 1998). Section A can be improved by reducing the number of necessary steps throughout the process flow of article B. In the process activity mapping (appendix C) there are currently 23 steps of which 16 are characterised as NVA and 18 are characterised as NNVA. All MMH are classified as both NVA and NNVA. Reducing NVA and NNVA will reduce time and distance spent on moving and handling material. Reducing the number of steps is possible through elimination of MMH, which in turn will reduce the need for transportation and storage. Elimination of MMH is possible through a vision camera inspecting the products, handling materials from one conveyor belt directly to another or by connecting the operations where no MMH is needed or robots lifting materials on and off pallets. The movement and handling of material are interrelated; as stated by Mathisson-Öjmertz (1998b), a suitable material handling system can facilitate efficient material flow (Mathisson-Öjmertz, 1998b).

There are several advantages of a well-designed MH system; effective support of operations (Hassan, 2010), reduced costs (Öjmertz, 1998) and improved material flow and handling (Green, et al., 2010). An outcome of reducing the number of lifting is better ergonomics with lowered risks of injuries. Repetitive lifting is strenuous and the working condition of running several machines simultaneously with great amount of MMH activities is stressful. Lean manufacturing should permeate through the entire organisation where improvements, regardless of size, are considered and implemented for continuous improvements. Therefore, it is important that operators are encouraged to be creative in proposing suggestions for improvements (Liker, 2004). The operators usually are the ones with the best knowledge of the processes and material handling.

5.2.3 Can a change in the layout of the production area result in improved flow and handling of material? (RQ3)

Suggestions for improvement of the material flow and the way the material is handled may require a change in layout.

The material movement from storage to production area is, according to Aiello et al. (2002), affected by the layout of the facility. The same applies with the material handling. The location of machines and pallets in production section A is affecting the movement and handling of material before, during and after each operation. The production process of article B is also affected since the operations should be located near and the layout of the production area should facilitate and support the material handling and movement (Drira, et al., 2007; Mulcahy, 1999). Decisions regarding changes of layout in production section A must be taken

Discussion

in consideration to their impact on the production processes as well as the material movement and handling (Aiello, et al., 2002). Changes in the layout can help improve the material movement and handling.

Both smaller and more extensive changes in the layout can be performed. Changing location of conveyor belts for in- and outgoing material to OP30 is a rather minor change, requiring minimal effort in time and money. On the other hand, investing in a palette system requires a greater investment. New palettes, robots programmed for handling material to and from palettes, and removal of conveyor belts are required. The most comprehensive layout change is to move OP50 which would require more time and a greater investment. However, the more extensive the change, the larger is the impact of improvement. Improving the flow and handling of materials will lower costs and time spent, while enabling increased productivity and profitability.

6 Conclusions

The purpose of this thesis was to explore options for material flow improvements and handling of material in production area. If necessary for improvements of material flow, a change in layout design would be recommended. The following are the concluding answers for each research question for this thesis:

RQ1: How can the movement of material from storage to production areas be improved?

- a. Having the right amount of equipment
- b. Closer storing of material
- c. Change in production planning

RQ2: In what way can the material handling be improved?

- a. Automated inspection
- b. Vision system with cameras of robots

RQ3: Can a change in the layout of the production area result in improved flow and handling of material?

- a. Changing locations of conveyor belts
- b. Connecting operations
- c. Rearrangement of operations

Based on the findings of the study, material flow and handling can be improved in several ways. Having the right amount of equipment required will ease both the material movement and handling. Distance of movement will be shortened by storing material closer to the operations and by producing the same type of product in all operations simultaneously. The MMH can be reduced by a vision camera inspecting measurements and robots picking materials from and placing on pallets. Handling material directly between operations without storing on pallets will reduce the MMH as well as the movement.

The material flow and the way the material is handled can further be improved by a change in the layout of the production area. Changing location of conveyor belts going in and out of OP30 will reduce distance of movement. Connecting conveyor belts between OP20 and OP30 will improve both the material flow and handling. The same applies if investing in vision systems with cameras where robots can pick materials from and place on pallets and/or palettes. Rearrangement of operations can ease the movement of material with ample space to move and handle the material.

6.1 Future research

The findings generated in this study could be a base for future research on material flow and handling, especially the measurements of MMH activities. The measurements of MMH are

Conclusions

calculated in relation to the production time of each operation. For future research, conducting a similar study of one operator during one shift could generate data for the percentage of a shift spent on MMH and movements of material. The impact improved material flow and handling has on the company's profitability is another suggested area for future research.

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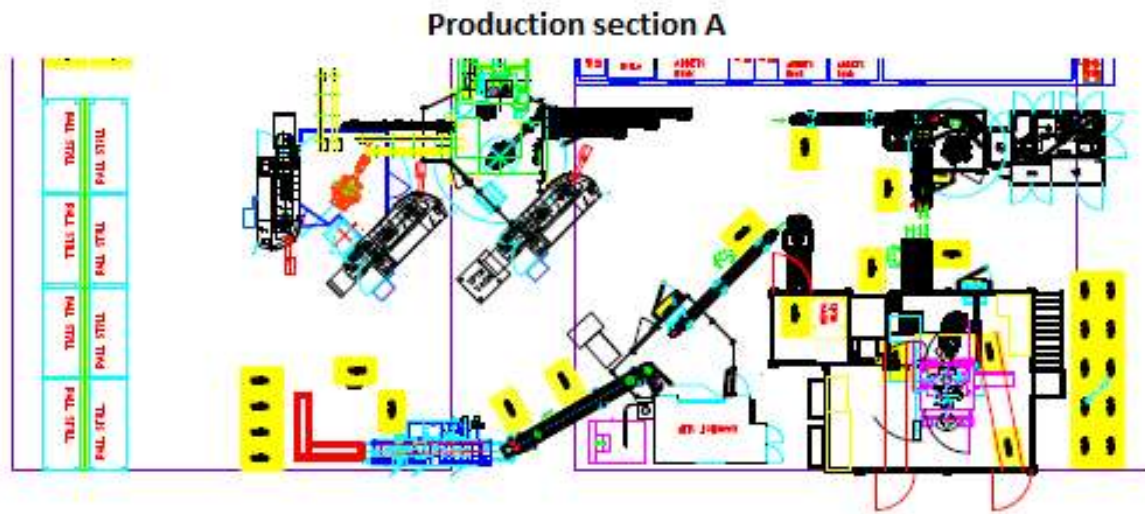
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8 Appendices

Appendix A: Production layout



Appendix B: Interview questions operators

Material flow

- Is there any movement that is unnecessary?
- Would it be more appropriate to use any other material handling equipment(s)?
- Could storing the materials closer to the machines reduce the handling and movement?
- In what way do you think the material flow can be improved?
 - Why?

Material handling

- Is there any handling activity that is unnecessary?
- Would it be more appropriate to use any other material handling equipment(s)?
- Are materials handled ergonomically?
- Are operators informed about ergonomics and taking it into consideration when handling material?
- In what way do you think the material handling can be improved?
 - Why?

Production layout

- Can a change in layout design improve the material flow and handling?
 - If; in what way?

Appendices

Appendix C: Activities during production process

Production process of article B, one batch of 96 parts												
Step	Flow	Equipment	Distance (metres)	Time (minutes)	Lifting (nr of times)	Chart symbol				Classification of activities		
						→	□	•	Δ	NVA	NNVA	VA
1 Transportation	→	Forklift	10									
2 MMH (L1)	□			4.52	96							
3 OP10 Turning	•	Machine										
4 MMH (L2+L3)	□			34.58	327							
5 Transportation	→	Forklift	28									
6 Storage	Δ											
7 Transportation	→	Forklift	29.5									
8 MMH (L4)	□			9.76	96							
9 OP20 Hardening	•	Machine										
10 MMH (L5)	□			6.62	96							
11 Transportation	→	Forklift	30									
12 Storage	Δ											
13 Transportation	→	Forklift	41									
14 MMH (L6)	□			5.51	96							
15 OP30 Broaching	•	Machine										
16 MMH (L7)	□			7.57	96							
17 Transportation	→	Forklift	44									
18 OP40 External operation	•											
19 Transportation	→	Forklift	17.5									
20 MMH (L8)	□			4.81	96							
21 OP50 Grinding, cleaning	•	Machine										
22 MMH (L9)	□			9.59	96							
23 Transportation	→	Forklift	3									
TOTAL			203	82.96	999	8 times	8 times	5 times	2 times	16 times	18 times	5 times
					203 m		82.96 min					

Chart symbol meaning

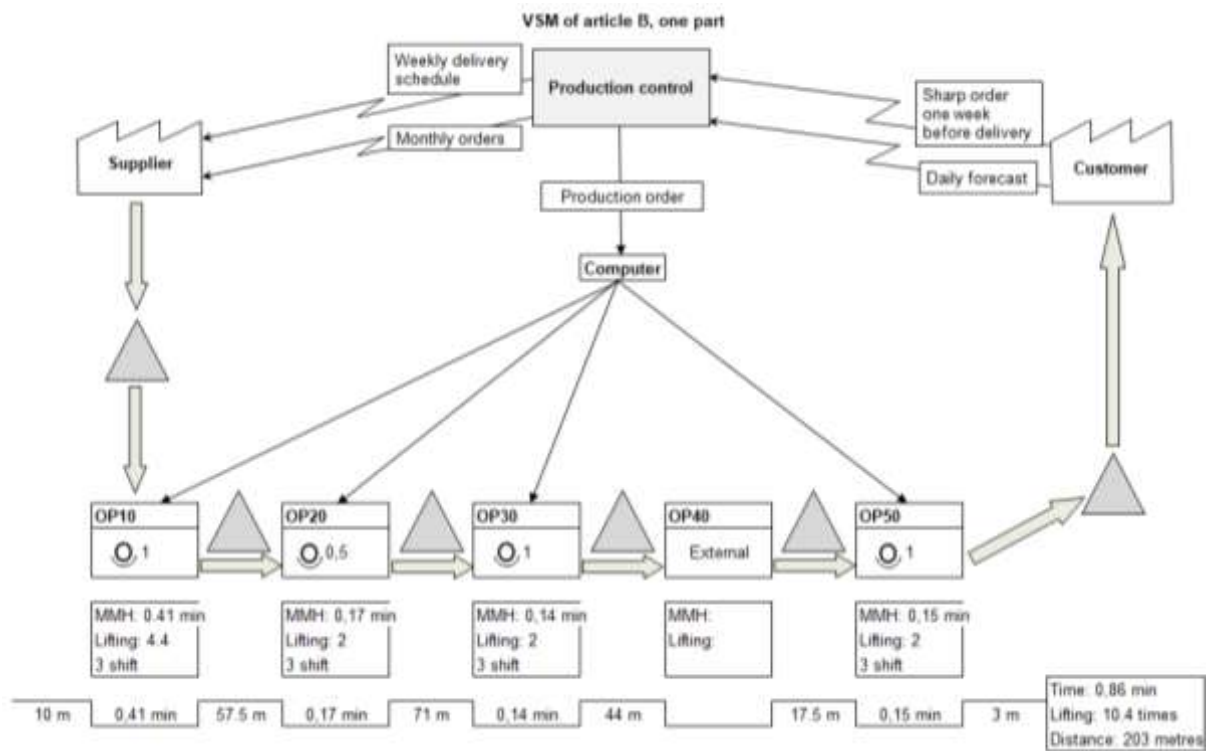
→ Transport

□ MMH

• Operation

Δ Storage

Appendix D: VSM of material flow



Appendices

Appendix E: Future state of activities during production process

Production process of article B, one batch of 96 parts												
Step	Flow	Equipment	Distance (metres)	Time (minutes)	Lifting (nr of times)	Chart symbol				Classification of activities		
						→	□	•	Δ	NVA	NNVA	VA
1 Transportation	→	Forklift	10			→	□	•	Δ			
2 OP10 Turning	•	Machine						•				
3 MMH (L3)	□			16.86	96		□					
4 Transportation	→	Forklift	18			→	□	•	Δ			
5 Storage	Δ								Δ			
6 Transportation	→	Forklift	19			→	□	•	Δ			
7 MMH (L4)	□			9.76	96		□					
8 OP20 Hardening	•	Machine						•				
9 OP30 Broaching	•	Machine						•				
10 MMH (L7)	□			7.57	96		□					
11 Transportation	→	Forklift	5			→	□	•	Δ			
12 OP40 External operation	•							•				
13 Transportation	→	Forklift	17.5			→	□	•	Δ			
14 MMH (L8)	□			4.81	96		□					
15 OP50 Grinding, cleaning	•	Machine						•				
16 MMH (L9)	□			9.59	96		□					
17 Transportation	→	Forklift	3			→	□	•	Δ			
TOTAL			72.5	48.59	480	6 times	5 times	5 times	1 times	6 times	12 times	5 times
			72.5 m 48.59 min									

Chart symbol meaning

- Transport
- MMH
- Operation
- Δ Storage

Appendix F: Future state of the VSM of material flow

