OULUN YLIOPISTO

FACULTY OF TECHNOLOGY

# IMPROVING INTERNAL LOGISTICS PROCESS WITH LEAN SIX SIGMA PROJECT

Jaakko Knuutinen

INDUSTRIAL ENGINEERING AND MANAGEMENT

Bachelor's Thesis

November 2018

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Supervisor: Osmo Kauppila

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# TIIVISTELMÄ OPINNÄYTETYÖSTÄ Oulun yliopisto Teknillinen tiedekunta

| Koulutusohjelma (kandidaatintyö, diplomityö) | Pääaineopintojen ala (lisensiaatintyö) |
|---|---|
| Tuotantotalouden koulutusohjelma | - |

| Tekijä | Työn ohjaaja yliopistolla |
|---|---|
| Knuutinen, Jaakko | Kauppila, Osmo |

Työn nimi

IMPROVING INTERNAL LOGISTICS PROCESS WITH LEAN SIX SIGMA PROJECT

| Opintosuunta | Työn laji | Aika | Sivumäärä |
|---|---|---|---|
| - | Kandidaatintyö | Marraskuu 2018 | 37 |

Tiivistelmä

Työn tavoitteena on tutkia, miten lean six sigmaa voidaan hyödyntää logistiikkaprosessin kehittämisessä ja miten sen käytännöntoteutus on mahdollista. Tarkoituksena on vähentää myöhästyneiden materiaalitoimitusten määrää tehtaan ja läheisen materiaalivaraston välillä. Työ suoritetaan tapaustutkimuksena, jossa ensin tehdään kirjallisuuskatsaus aiheesta tutkimalla alan tieteellisiä tutkimuksia ja julkaisuja. Tämän jälkeen suoritetaan käytännön prosessinkehitysprojekti yrityksessä. Projektin aikana sovelletaan kirjallisuudesta opittua tietoa ja käytetään lean six sigman työkaluja, joista annetaan myös esimerkkejä.

Työn tuloksena saatiin kehitysehdotuksia, jotka tekemällä myöhästyneiden toimitusten määrää saataisiin vähennettyä. Projektin rajallisen aikataulun takia näitä ehdotuksia ei ehditty viedä kokonaisuudessaan käytäntöön asti, joten ei ollut mahdollista raportoida todellisia taloudellisia säästöjä. Vuosittainen pessimistinen arvio kehityspotentiaalista oli noin 485 000 euroa. Tutkimuksen tulokset ovat hyvin hyödynnettävissä, sillä projektissa käytettyjä työkaluja voidaan hyödyntää monenlaisissa kehitysprojekteissa toimialasta riippumatta. Kehityspotentiaali ei ole suoraan yleistettävissä muihin logistiikkaprosesseihin, mutta samankaltaisia ongelmia ilmenee monien yritysten prosesseissa, joten tämä tutkimus voi olla hyödyksi myös niiden ratkaisemiseen.

Muita tietoja

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# ABSTRACT FOR THESIS

University of Oulu Faculty of Technology

| Degree Programme (Bachelor's Thesis, Master's Thesis) | | Major Subject (Licentiate Thesis) | |
|---|---|---|---|
| Bachelor's Degree in Industrial Engineering and Management | | - | |
| Author<br>Knuutinen, Jaakko | | Thesis Supervisor<br>Kauppila, Osmo | |
| Title of Thesis<br>IMPROVING INTERNAL LOGISTICS PROCESS WITH LEAN SIX SIGMA PROJECT | | | |
| Major Subject<br>- | Type of Thesis<br>Bachelor's Thesis | Submission Date<br>November 2018 | Number of Pages<br>37 |

Abstract

The objective of this study is to investigate how lean six sigma can be used in a process improvement project, and how to apply lean six sigma in a real-life situation. The task is to decrease the amount of late deliveries to a factory from a nearby logistics facility, where production materials are stored in. The study will be performed as a case study. The case study begins with a literature review, where scientific publications of the subject are studied. After this, a real-life process improvement project will be carried out in a company. During the project, the learnings from the literature and the tools and methods of lean six sigma will be applied. There will also be examples given on the application of lean six sigma.

As a result of this study, suggestions for improvement were made. Implementing these suggestions would help to reduce the amount of late deliveries. Due to the limited time of the project, these suggestions could not be completely carried out to be used practically during the case study. Therefore, it was not possible to report the actual benefits of these improvements. However, a pessimistic annual assessment of the potential benefit was 485,000 euros. The results of this study can be used very well because the tools used in the project can be applied to any field of business. The potential benefit for the process under investigation is not entirely generalizable. However, many companies face the same kind of problems in their processes, for which, this study can be of help to.

Additional Information

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# BACKGROUND FOR THE STUDY

This study focuses on how to apply a lean six sigma project and how it can be used to improve the process of material flow and internal logistics in a factory environment. Why is this an intriguing subject? Lean six sigma has been stated to save companies a lot of money. For example, Antony (2006) gives an example from Motorola which spent 170 million dollars to educate and train their employees in six sigma and saved 2.2 billion dollars during a period of three years. Another reason for this subject is that it focuses on a logistics process which is a service process, instead of a manufacturing process.

There has been a lot of studies on how to apply lean six sigma projects to manufacturing processes, but not nearly as many focusing on service processes. This brings us to another reason why this subject is interesting and useful – there is a lot of potential in improving a logistics process. According to Dahlgaard & Dahlgaard-Park (2006), improving non-manufacturing processes is one of the weakest areas in the quality system of nearly every company. In addition, Jim Wu (2002) emphasizes the importance of logistics because it supports other critical actions in a firm's operations by transporting needed materials for these actions. Therefore, any savings made in logistics or material flow process will be substantial.

The problem in this study is the late deliveries of material that come to a factory from a nearby logistics facility. The objective of this study is to find a way to improve the material flow and logistics process by using the methods of lean and six sigma in an improvement project. To study these objectives, the following research questions have been set:

1. How to apply a DMAIC project in a real-life situation?
2. Can a lean six sigma project be used to improve a service process?

The study will be carried out as a case study. Methods to fulfil the task is to study based on the current literature, what is lean six sigma all about and what kind of tools does it include. After that, a real-life project, for a period of three and a half months, will be attended, where the problem will be investigated and solved with the information gathered from the literature and by applying the methods of lean six sigma. Therefore, this study begins with a literature review, where lean and six sigma will be examined. Afterwards, the study continues to introduce all the phases and actions done in the real-life lean six sigma project and, lastly, there will be a summary of the whole study in the end.

# LITERATURE REVIEW

## 1.1 Lean

Lean is a management philosophy that focuses on creating more value to the customer and making improvements with special focus in reducing waste (Dahlgaard & Dahlgaard-Park, 2006). Lean thinking was first developed between the 1940s and 1970s by Taiichi Ohno in Japan. Taiichi Ohno worked for Toyota and later became a vice president in the company. The system Taiichi Ohno created was called the Toyota Production System. (Ōno, 1988) Toyota Production System was primarily a human-based system that involved people with continuous improvements, the foundation being leadership and empowerment through education and training (Dahlgaard & Dahlgaard-Park, 2006). This system was later introduced to the West in 1990 by Womack & Jones (2007) in the first edition of their book "The Machine that Changed the World" and became the philosophy known today as lean thinking or lean manufacturing.

Lean production can be described as "a multi-dimensional approach that encompasses a wide variety of management practices, including just-in-time, quality systems, work teams, cellular manufacturing, supplier management, etc. in an integrated system" (Shah & Ward, 2003). Lean focuses on individual product and its value stream, and on eliminating all waste in all areas and functions in the system, which is the target of lean thinking (Womack & Jones, 2003). Womack and Jones (2003) have also stated the five principles of lean thinking which are: value, value stream, flow, pull, and the strive for perfection. Each of these principles contains tools and techniques that can be used to add value and remove waste from business' processes, thus creating a company more effective in serving its customers and making money.

### 1.1.1 Value and value stream

In lean thinking, every activity is divided into three categories: value-adding, necessary non-value-adding and non-value-adding activities. In value-adding activities, a product or service is provided to the customer at the right time with an appropriate price, as defined by the customer. (Bhasin & Burcher, 2006). Value-adding activities are also done only once which means that the job must be done right for the first time. Anything else is considered as waste and should be removed to the minimum. While both necessary and non-necessary non-value-adding activities are waste, only the non-necessary can be eliminated right away. Necessary non-value-adding activities are activities that must be done because of matters such as safety, laws, or specifications. Defining value for products or services is the first thing to do in lean management. Value must be defined by the customer and needs to be specific for each product. (Womack & Jones, 2003)

Waste, *muda* in Japanese, is anything that does not add value to the product or service being produced, increasing its cost (Dahlgaard & Dahlgaard-Park, 2006). There are seven forms of waste whose name vary depending on the source. The seven most commonly used terms for waste are overproduction, defects, unnecessary inventory, inappropriate processing, excessive transportation, waiting and unnecessary motion (Pepper & Spedding, 2010). In addition to these common forms of *muda*, there is the *muda* of intellect. This means the inability to completely utilize the skills of the people in an organization. (Dahlgaard & Dahlgaard-Park, 2006)

After identifying value, the next step in progress towards lean manufacturing is to identify the product's or service's value stream (Álvarez, Calvo, Peña, & Domingo, 2009). Womack & Jones (2003) have explained value stream in their book "Lean Thinking" as "the specific activities required to design, order and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer". This means that it isn't enough to only review one's own organization, but all the other organizations involved should also be recognized. The activity of identifying a value stream is called value stream mapping. Pepper & Spedding (2010) explain in their literature review of lean six sigma that it is not enough to map the value stream. Instead, in a lean operation, the value stream map should be applied systematically before other lean tools are used (Pepper & Spedding, 2010). Value stream map is a commonly used analysis tool in lean operations, an example of a value stream map can be seen from Figure 1.

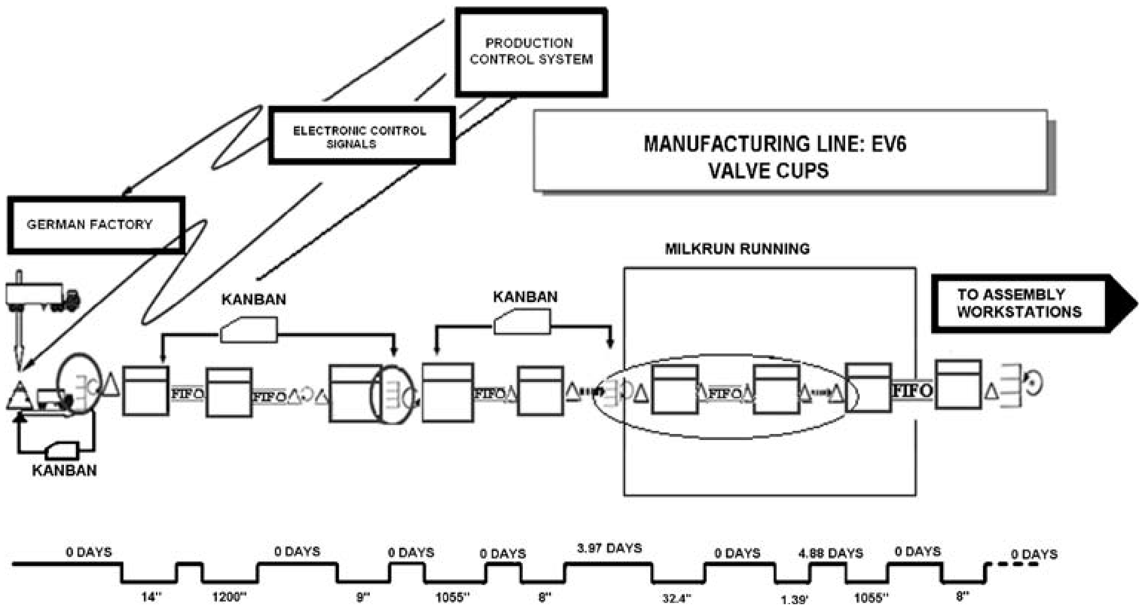



Figure 1. An example of a value stream map. (Álvarez et al., 2009)

### 1.1.2 Flow and pull

Lean production was first developed to increase the velocity of product flow by the elimination of all non-value-added activities (Arnheiter & Maleyeff, 2005). The idea of flow is to make the value flow without interruptions. (Womack, Jones, & Roos, 2007). This means that products are not made in batches, which often wait in queues or inventories before the next production step starts (Dahlgaard & Dahlgaard-Park, 2006). Creating flow is essential for lean to be successful. Lean has many different tools and most of them need to be utilized to create flow within a system. The most important tools for establishing flow are Kanban system, single minute exchange of dies (SMED), layout with flexible workstations, and single-piece-flow systems. (Bhasin & Burcher, 2006)

One method to manage production flow is Just-in-Time or JIT production (Womack & Jones, 2003). The idea behind JIT production is that everything is done exactly when the next step in the process, or the customer, need it, not before nor after the absolute need for it (Arnheiter & Maleyeff, 2005). JIT philosophy does not only consider production, instead, it can be applied to all of the operations within an organization where waste exists (Jim Wu, 2002). JIT system reduces waste in multiple ways. Dahlgaard & Dahlgaard-Park (2006) explain, how a JIT system reduces waste by reducing the amount of space needed, no extra parts needed, and the immediate discovery of defects. At first, it is easy to think that JIT systems only reduce the waste of inventory. However, Jim Wu (2002) states that the primary focus in the reduction of waste with a JIT system would be the time from customer order to delivery. This does not, however, mean that there would not be any reduction in the *muda* of inventory.

Another important part of lean is the ability to pull production. Lean organizations practice pull production instead of the traditional push production (Arnheiter & Maleyeff, 2005). In push production products are usually made according to sales forecasts. In pull production, however, products or services are made only when the customer, external or internal, needs them (Womack & Jones, 2003). Pull production is usually applied with a control that applies Kanban. Kanban is a type of card that is used as a tool to communicate between production lines (Dahlgaard & Dahlgaard-Park, 2006). In this mechanism, a predefined level of buffer stock of parts needed for an operation is replenished (Satoglu & Sahin, 2013).

### 1.1.3 Strive for perfection with continuous improvement

Womack and Jones (2003) define perfection as "the complete elimination of *muda* so that all activities along a value stream create value". They also explain that even though perfection can never be achieved, organizations should continuously attempt to reach it. This is the foundation of continuous improvement. (Womack & Jones, 2003) Continuous improvement is the continual pursuit of improvements in quality, cost, delivery and design (Laureani, Antony, & Douglas, 2010). Efforts focused towards the reduction of waste are pursued with continuous, incremental improvement or *kaizen* events, as well as radical improvements, called *kaikaku.* While both *kaizen* and *kaikaku* reduce *muda*, *kaizen* events are smaller and done more frequently than *kaikaku* events which are generally reserved for the initial rethinking of a process. (Womack & Jones, 2003)

The most important factor for any of the continuous improvement efforts is the support from management. Management needs to actively communicate and support the employees. Employees also need to be educated and empowered. (Pepper & Spedding, 2010) Sustaining a lean operation, a company must review their organizational values to go through with the culture change and get the workers to work towards the idea of non-stopping continuous improvement (Womack & Jones, 2003). Bhasin & Burcher (2006) explain that when fast results are possible, lean should be a long-term strategy, in order to get its full benefits.

According to Dahlgaard & Dahlgaard-Park (2006), lean management often focuses too much on training people on tools and techniques rather than building the right company culture by focusing on the human factors. This argument is supported by Pepper & Spedding (2010) who noted that implementing 5S before anything else may drive the focus off from the big picture and other viable lean tools that would lead to more sustainable changes within a system. 5S is a lean tool where everything has its own standardized place and all the working stations are kept clean. This reduces the clutter, inefficiency, and variability in the working environment. (Bhasin & Burcher, 2006)

## 1.2 Six Sigma

### 1.2.1 History and meaning of Six Sigma

The concept of Six Sigma was originated by Motorola Inc. in the USA in 1987. Motorola was facing a threat from Japanese electronics manufacturers and had to drastically improve their final product quality. (Linderman, Schroeder, Zaheer, & Choo, 2003) Six Sigma can be defined as an organized and systematic methodology for process improvement that relies on data-driven methods to achieve stable and predictable process results, reducing process variation and customer-defined defects (Laureani et al., 2010). Schroeder, Linderman, Liedtke, & Choo (2008) go even further in their definition of Six Sigma: “Six Sigma is an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives.” While there are similar aspects to these definitions, the latter highlights the use of specialists, a structured method, and performance metrics. From a wider point-of-view, Six Sigma programs focus on the customer, recognition that quality is the responsibility of everyone, and the emphasis on employee training (Arnheiter & Maleyeff, 2005) .

During the threat of the Japanese electronics industry, Motorola set a goal of only 3.4 defects per million opportunities for critical to customer processes. This goal is ±6 S.D. from the mean. (Linderman et al., 2003) Therefore, as a term, “six sigma” refers to a statistical measure of defect measure within a system, aiming to 3.4 defects per million opportunities (Pepper & Spedding, 2010). A post office can be used as an example of Six Sigma quality. If the post office was working at 99 per cent quality, for every 300,000 letters delivered, there would be 3,000 misdeliveries, compared to only one misdelivery at a Six Sigma level, which equals to 99.99966 per cent quality (Pande, Cavanagh, & Neuman, 2000). The relationship between defect rate and Process Sigma Level can be seen from Figure 2.

Linderman et al. (2003) and Arnheiter & Maleyeff (2005) note that not all processes should work on a six sigma level. Only the processes that are the most critical to the customer, in other words, strategically important, should operate on a six sigma level. This is because the effort and difficulty increases exponentially as process Sigma increases. It is important to also keep in mind, however, that some very critical processes should even operate beyond six sigma level. The appropriate process Sigma level for each process depends on its strategic importance and the relation of the benefit versus the cost of improvement (Linderman et al., 2003).

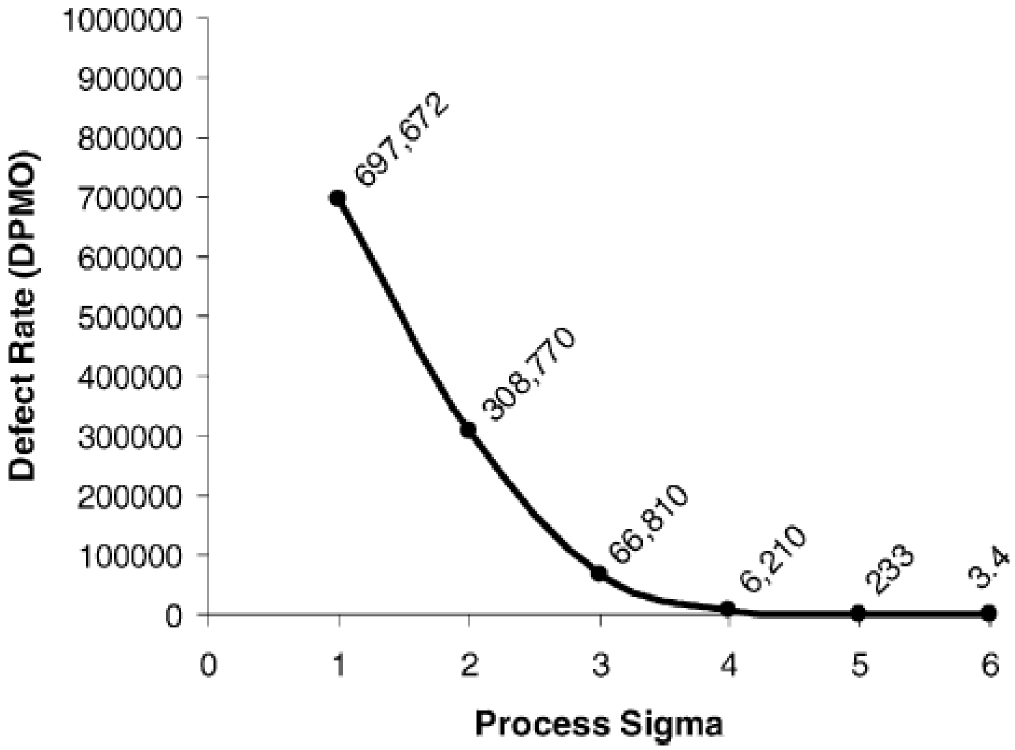



Figure 2. Defect rate vs. Process Sigma level (Linderman et al. 2003)

### 1.2.2 Organization structure of Six Sigma

Even though Six Sigma is very focused on data and statistics, Pepper & Spedding (2010) found that data, people, and the overall goal of improvement are equally interrelated. This means that a company should not purely focus on data analysis tools, but rather focus on the cultural aspect of improvement. The same observation of the importance of applying a company culture was made by Dahlgaard & Dahlgaard-Park (2006) in their literature study. As with many other quality philosophies, the implementation of Six Sigma needs to be driven by the senior leadership of the company. The leaders should be aware that to be successful, both technical and behavioural insight is required (Linderman et al., 2003).

Schroeder et al. (2008) explain that Six Sigma uses an organization system that trains improvement specialists to achieve improvement goals which reduce variation in processes and improves performance metrics. According to Arnheiter & Maleyeff

(2005), this structured system is used to ensure the effective training of employees. The specialists in Six Sigma are called Green Belts, Black Belts, Master Black Belts, and Project Champions (Pepper & Spedding, 2010). Linderman et al. (2003) emphasize that "intensive and differentiated training is an integral part of the Six Sigma approach." In addition, this kind of organizational structure is unique to Six Sigma (Schroeder et al., 2008). This system allows the specialists to have an organization-wide view of continuous improvement and an in-depth knowledge of the business processes (Zu, Fredendall, & Douglas, 2008).

According to Linderman et al. (2003), Black Belts are individuals who work on Six Sigma projects full-time and lead projects. They typically receive around four weeks of training in Six Sigma (Schroeder et al., 2008). In addition, Schroeder et al. (2008) note that "Black Belts play an essential role in Six Sigma because they bridge the gap between senior management and project improvement teams." In Six Sigma roles, the people in senior management, such as vice presidents, usually serve as Project Champions.

Project Champions play an active role in the define phase and help to define the problem together with the project team (Schroeder et al., 2008). As Linderman et al. (2003) explain, they are people who identify strategically important projects to work on and do not receive much detailed training, only the basic orientation to Six Sigma. Nevertheless, Project Champions play an important role in Six Sigma. According to Senapati (2004), the selection of correct improvement projects is critical for success in Six Sigma.

Master Black Belts receive more training than Black Belts and usually work as internal consultants or instructors. Their main task is to provide technical assistance and mentoring to other improvement specialists. Green Belts are usually individuals who have substantial knowledge of the process. They receive around two weeks of training in Six Sigma and work on improvement projects part-time, often in supporting roles. Green and Black Belts also act as change agents who spread the Six Sigma philosophy throughout the organization. (Schroeder et al., 2008)

As suggested by Schroeder et al. (2008) these different improvement specialists should work together and form a parallel-meso structure in a company. Parallel-meso structure is demonstrated in Figure 3. Six Sigma role structure supports the use of a structured improvement procedure in Six Sigma (Zu et al., 2008). The structured belt system in Six Sigma is, however, also criticised for its possibly expensive training and implementation of the belt system, driving the focus out of the present issues, and facing the risk of becoming a consultancy practice (Senapati, 2004).

In improvement projects, these improvement specialists form a project team that is used to make improvements. The project team consists of a Black Belt, a Project Champion, a Green Belt, and a Process Owner at the minimum (Schroeder et al., 2008). Often there are also other members in this team. For example, a person from the financial department or other specialists. It is important to note, however, that not everyone in the team works actively throughout the project. Different roles are active during specific phases of the project, as explained by Schroeder et al. (2008).

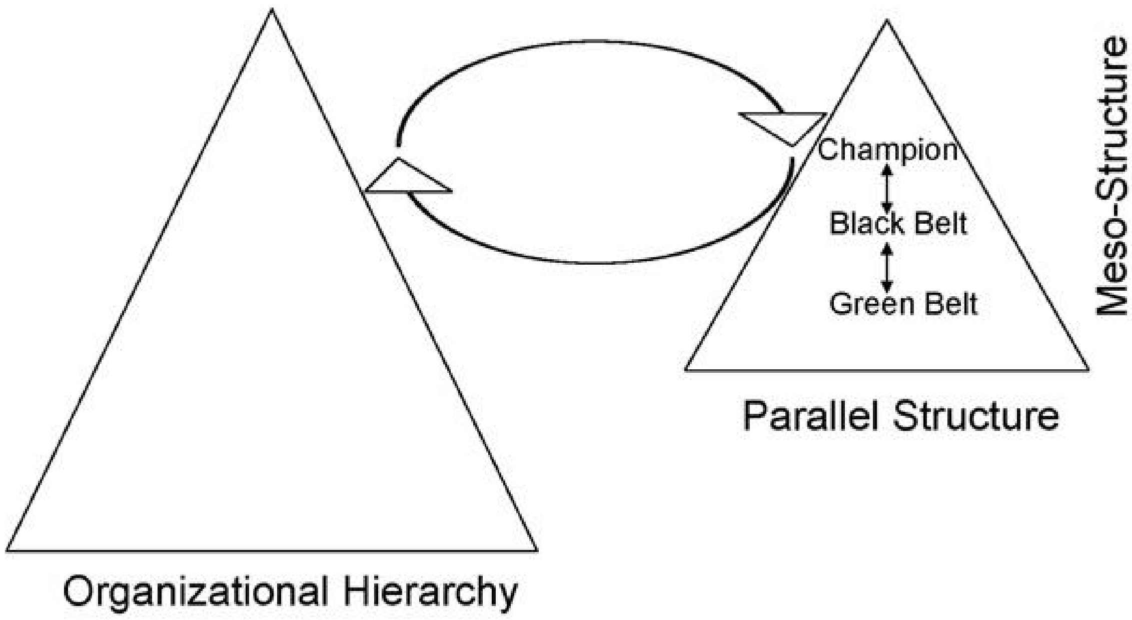



Figure 3. Parallel-meso organization structure (Schroeder et al. 2008)

### 1.2.3 DMAIC cycle for improvement projects in Six Sigma

DMAIC stands for Define, Measure, Analyse, Improve, and Control which are the structured process steps for process improvement projects in Six Sigma (Pepper & Spedding, 2010). Sometimes DMAIC is also called as DMAICR where the "R" stands for Realize or Reporting (Senapati, 2004). In this step, the benefits of the re-engineered process are reported. This is, however, done in any Six Sigma project even though the

Realize phase is not officially used. DMAIC method provides a metaroutine for solving problems and improving processes, which helps to avoid jumping to conclusions and helps to ensure an adequate search of alternative solutions (Schroeder et al., 2008). According to Linderman et al. (2003), it is a popular method in process improvement. The DMAIC process is patterned after the plan, do, check, act (PDCA) cycle. However, it has specific tools and techniques for each step, which is unique to Six Sigma. (Linderman et al., 2003) In order to effectively follow the DMAIC cycle, training of key staff is critical, as is the buy-in of senior management for the current project to be successful (Pepper & Spedding, 2010). The importance of involving the correct people is also noted by Schroeder et al. (2008), who explain that different organizational members are used in all or only one of the DMAIC phases.

Define phase is the first phase of the DMAIC project. In this phase, a project team is constructed of all the key stakeholders, the problem that needs to be solved is defined, and a SIPOC, Supplier-Input-Process-Output-Customer, process map is made. All this information is then gathered on a project charter which clearly illustrates the roles and responsibilities of all participants of the project. (Antony, 2006; Senapati, 2004) A clear definition of the problem and following the chosen method is critical for success, no matter what kind of method is used (Linderman et al., 2003). At the beginning of a Six Sigma project, it is important to start working with a clear state of mind and without any prejudice of the solution (Laureani et al., 2010).

Measure phase is the next step in the DMAIC cycle. In measure phase, the following activities are done: the current performance of a process is measured, objects of measurement are decided, strengths and weaknesses are identified based on measurements, and benchmarking is done compared to other processes (Laureani et al., 2010). The measurement of current process performance generally involves calculating the DPMO and capability of the process (Laureani et al., 2010). In addition, key metrics for the process together with clear and specific quantitative targets are often set during the measure phase when data of the process is collected (Linderman et al., 2003).

The third step in the DMAIC cycle is the analyse phase. In this phase, the behaviour of a process is analysed. The main task of the analyse phase is to uncover the root causes of defects in the process (Laureani et al., 2010). To get to the root causes, the data of process performance needs to be analysed. This is done with a variety of tools and techniques, for example, graphical tools such as a Pareto chart (Laureani et al., 2010). Antony (2006) adds to these steps that also an estimation of financial benefits should be made. Since root causes are the factors in process variability that cause defects, they should be prioritized for further investigation.

The fourth step in the DMAIC cycle is the improve phase. As the name suggests, improvements are planned and made in this phase. Improve phase begins with developing potential solutions to the problems found in the earlier phases (Laureani et al., 2010). Solutions can be found by brainstorming and "walking the process" which means observing the process in action, as done by Laureani et al. (2010) in their study. After developing a number of potential solutions, their impact needs to be evaluated. The evaluation can be done by using tools and techniques such as a criteria-decision matrix, simulations, and experiments usually with a pilot group (Laureani et al., 2010). The solution that has the highest impact on customer satisfaction and bottom-line savings to the company should be prioritized, and the resources needed to make the improvement need to be determined (Laureani et al., 2010). After comparing different solutions, the best solutions are chosen and implemented. After improvements are made, the sigma value of the new process is calculated to validate that an improvement has been made (Laureani et al., 2010).

The final phase in the DMAIC methodology is the control phase. This is when the project is finalized and is handed to the project owner. Before a handover can be made a control plan must be in place. A control plan is a document made by the project team which lists all the corrective actions to sustain the improved process, along with the new standards and procedures to ensure long-term gains (Laureani et al., 2010). In a case study made by Laureani et al. (2010), a p-chart was used to monitor and sustain the gains. Since the control phase is the last phase in the methodology, financial gains from the improvement must be reported. Sometimes this activity has its own "Realize" or "Reporting" phase but the activities remain the same. The report should include any cost savings or avoidance, and benefits made with the improvement. These reports should be published internally or externally or for both. (Laureani et al., 2010) After all the documentation and reporting is done the process is handed over to the process owner.

As previously mentioned, different members of the organization participate more actively during different phases of the DMAIC cycle. For example, black belts are active throughout the project, but green belts take an active role during the measure, analyse, and improve steps (Linderman et al., 2003). Even though some companies might have a little bit of difference in the steps for the DMAIC procedure, like adding the sixth "Realize" step, it does not change the final result much. As Linderman et al. (2003) explain: "Whatever method is chosen, however, it is important that the method be carefully followed and a solution not offered until the problem is clearly defined. Data and objective measurement is critical at each step of the method." The importance of data and metrics during the problem solving is also emphasized by Zu et al. (2008), who found that the structured improvement method in Six Sigma helps to ensure that project teams use data and metrics during the process of solving the problem. Based on this finding Zu et al. (2008) propose that the use of structured improvement is associated positively with focus on Six Sigma metrics, which in turn is associated positively with product or service design and process management.

### 1.2.4 Performance metrics in Six Sigma

Six Sigma stands out from TQM and other quality and operational performance management philosophies by its focus on business performance metrics. In Six Sigma, an organization is led by quantifying improvements made in performance metrics specific to an improvement project. (Pepper & Spedding, 2010) The use of performance metrics gets support from Linderman et al. (2003) in form of setting challenging goals for improvement projects. They found out that appropriate and challenging, but not too overwhelming, goals improve the focus and commitment to the project to motivate performance. According to Antony (2004), Six Sigma focuses on measurable financial returns in a sequential and disciplined manner.

Using performance metrics provides quantitative data on product quality and process performance which can be used to enhance product or service and process management (Zu et al., 2008). Used metrics are selected based on what is critical from the customer's point of view (Linderman et al., 2003). Linderman et al. (2003) explain how metrics are used to guide the improvement team with clear and explicit goals, encouraging team member to make more effort, become more persistent, and focus on relevant activities to reach the set goal. They introduce metrics such as process Sigma, critical-to-quality, defect measures, and 10x improvement measures. Linderman et al. (2003) continue explaining that usually, the first thing to do is to measure process Sigma which is then transformed to DPMO for the process. DPMO is then used as a goal for defect reduction together with the 10x improvement rule, where the idea in this example is to improve the DPMO measurement by 10. For example, a goal for DMPO of 66,000 would be 6,600 with the 10x improvement rule. (Linderman et al., 2003) This kind of metrics are used by the improvement teams to monitor the process over time, making the quality problems visible and enabling a quick response from the teams if needed (Pande et al., 2000). Zu et al. (2008) suggest that focusing on performance metrics is positively related to product or service design and process management.

Although it is important to identify performance metrics in Six Sigma, challenges may occur in measuring performance in a service process. In Six Sigma, it is the customer's task to define a defect, and improvements are made based on these defects (Linderman et al., 2003). In a service business, a defect may be defined as anything the customer does not need or expect. This makes it challenging to use defects when calculating the six sigma capability of a process. (Antony, 2006)

# THE APPLICATION OF LEAN SIX SIGMA

This case study was conducted during a project that focused on improving material flow to the factory from a nearby external storage facility. The project was a green belt project, which is required for a person to become certified as a green belt in Lean Six Sigma. Therefore, it followed the DMAIC project cycle of Lean Six Sigma. The project was carried out in 2018 from May to August, lasting approximately three and a half months.

The case study took place in ABB's transformer factory located in Vaasa. The factory manufactures special transformers and reactors for various industries. If compared to car manufacturing factories, the special transformer factory in Vaasa could be compared to a sports car factory. This is because of the complexity and relatively low volume of the products when compared to other transformer factories. Most of the transformers produced in the factory are quite large. To give some insight, the average dimensions for an ordinary transformers or reactors are 3.5 meters height, 3 meters width, and 4 meters length. However, these dimensions vary greatly depending on the transformer.

The storage facility is located near the factory. Distance to the factory is approximately 250 meters. During midway of this project, the logistics activity was moved to a third-party supplier. This decision was not based on activities of this study. However, the decision gains some support from Jim Wu (2002) who reported that based on a mail survey of the 500 largest manufacturers in the U.S., the use of a third-party logistics supplier provides reduced cost, improved productivity, and improved service.

The process of material flow is operated with ABB's internal software called "Kotiinkutsu". The name roughly translates to "call to home" in English. This software is made specifically for the factory this study took place in. From the software, one can select to order all of the components used to produce a transformer that are stored in the logistics facility. For all the components, a specific date and time can be selected, as much in advance as one can plan their work pace. Kotiinkutsu also gathers data such as request time, requested time, delivery time, material type, and amount of material of all the orders made, to mention a few. This data was gathered and analysed during the different steps of the DMAIC project cycle.

## 1.3 Define phase

In the beginning of the project, a project team was formed, but only unofficially. This means that the people in the project team worked together, but there was no official team allocated for the project as it is usually the case in Lean Six Sigma projects according to literacy. In addition, there was no black belt in the team. The project team consisted of a green belt, executive sponsor, and other team members who were the production supervisors for different production areas. The project was led by the green belt with support from other team members.

The project began from a state where no clear problem was defined, but an improvement for the material flow was needed. Therefore, the very first thing needed to do in the project was the same as in any Lean Six Sigma project, define the problem that needs to be solved. In order to be able to create a clear definition of the problem, the current process for material ordering was studied. This was done by interviewing people from the production and logistics, both workers and supervisors, and walking the process to learn how it worked. Based on these interviews a high-level process map was made of the current process. This process map is introduced in the SIPOC process map in Figure 4. In addition to the process flow, the SIPOC process map shows the suppliers, inputs, outputs and customers (internal in this case) of the process. After speaking with various individuals, the following main problems arose: the material ordered from the storage facility stacked up in the factory, taking up a lot of space, and too much material was ordered when compared to the actual demand by production during that time.

After the problem and the current process at the time were defined, some objectives to solve these problems were set for the project. The objectives were to reduce late deliveries, to reduce amount of material stored in the factory, and to smoothen the material flow. Finally, a project charter where all the above information was gathered to, was created.

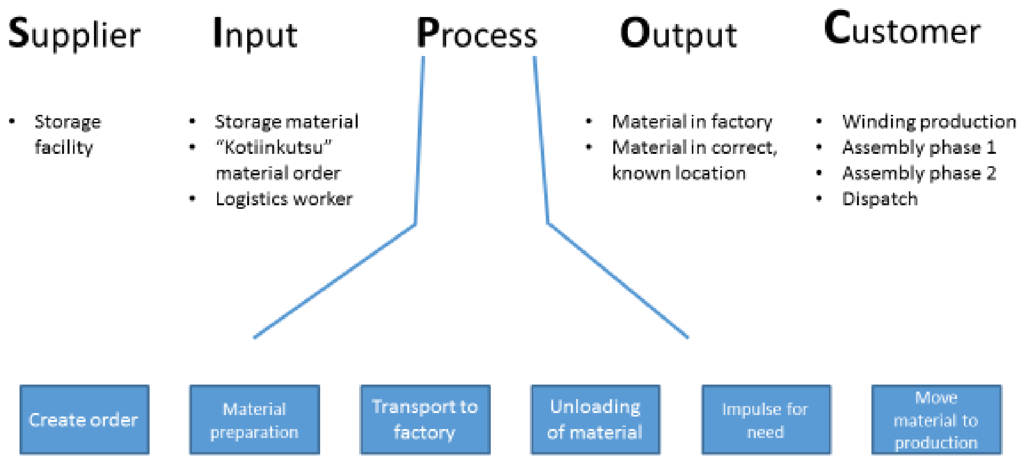



Figure 4. SIPOC map of the process in the beginning.

## 1.4 Measure phase

In order to be able to reach the objectives set in the define phase, investigation of current process performance was conducted by measuring the process with data gathered from the Kotiinkutsu software. To begin the measure phase, the process sigma level was measured first, as it was suggested by the literacy. Based on data from a period of five months, the yield rate was found to be 73.93%, thus giving a process sigma level of 2.14. Even though this process does not need a six sigma level execution rate, the result was still quite alarming. To put it simply, approximately every fourth delivery was late.

A second measurement was made during a small study in the logistics facility. For this study, different tasks of the work process in the logistics were defined, and the current activities of the workers were marked in a form. For a period of three working days, the workers performing tasks were observed, and their actions were recorded to the form. These observations were made in 10-minute rounds. Based on this study the time usage of different tasks in logistics was measured. At the same time, it was possible to see the process in action.

Other current performance measurements were made with the data from Kotiinkutsu. First, an I-MR chart of material deliveries to the factory during a period of three months was created. This I-MR chart can be seen in Figure 5. Based on the MR or moving range chart, it was possible to find out that the process was not in control. This is because some of the values on the MR chart do not stay within the control limits. Therefore, the control limits for the individual value chart are not accurate. In addition, it was possible to see from the chart that there was a lot of variance in the material flow. This could explain the unstableness of working time in the logistics facility.

The next measurements of data gathered from Kotiinkutsu software were a process capability analysis and a boxplot analysis of material deliveries to the factory in a three-month period. Looking at the capability analysis in Figure 6, it can be noticed that there is a long tail in the data that is out of the specification limits set for the process. This finding again pointed out that the process was not performing as it should. After this, a boxplot analysis was made, which compared the number of material deliveries on each working day of the week. The boxplot is shown in Figure 7. It was found out that Tuesday had the largest variance, whereas Wednesday seemed to have the lowest variance.

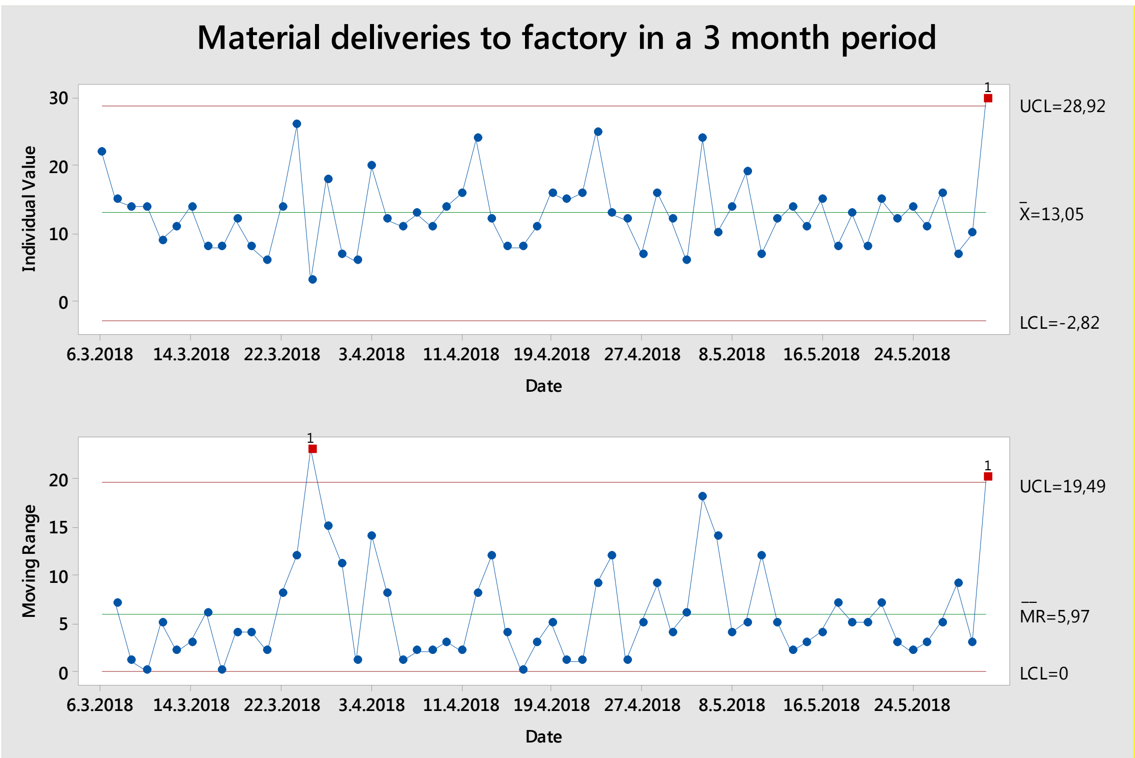



Figure 5. I-MR chart of material deliveries to the factory in three-month period.

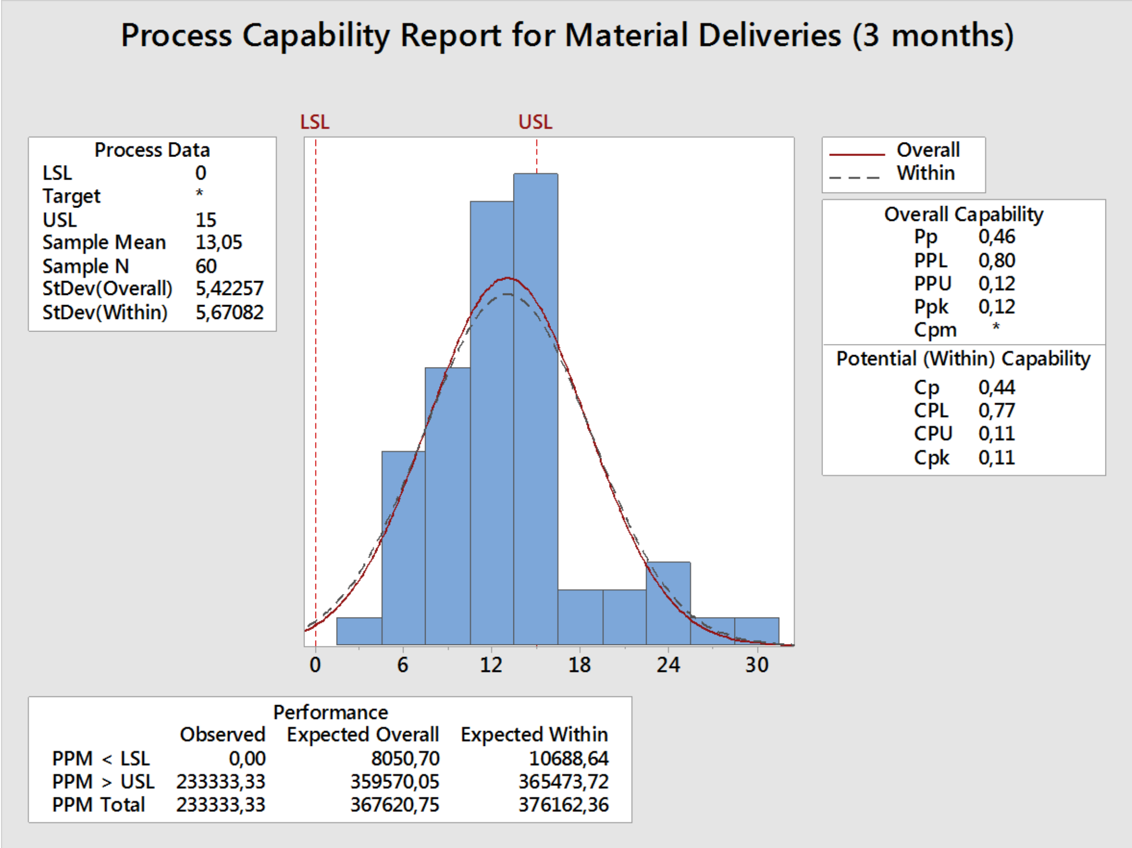



Figure 3. Process capability for material orders in a three-month period.

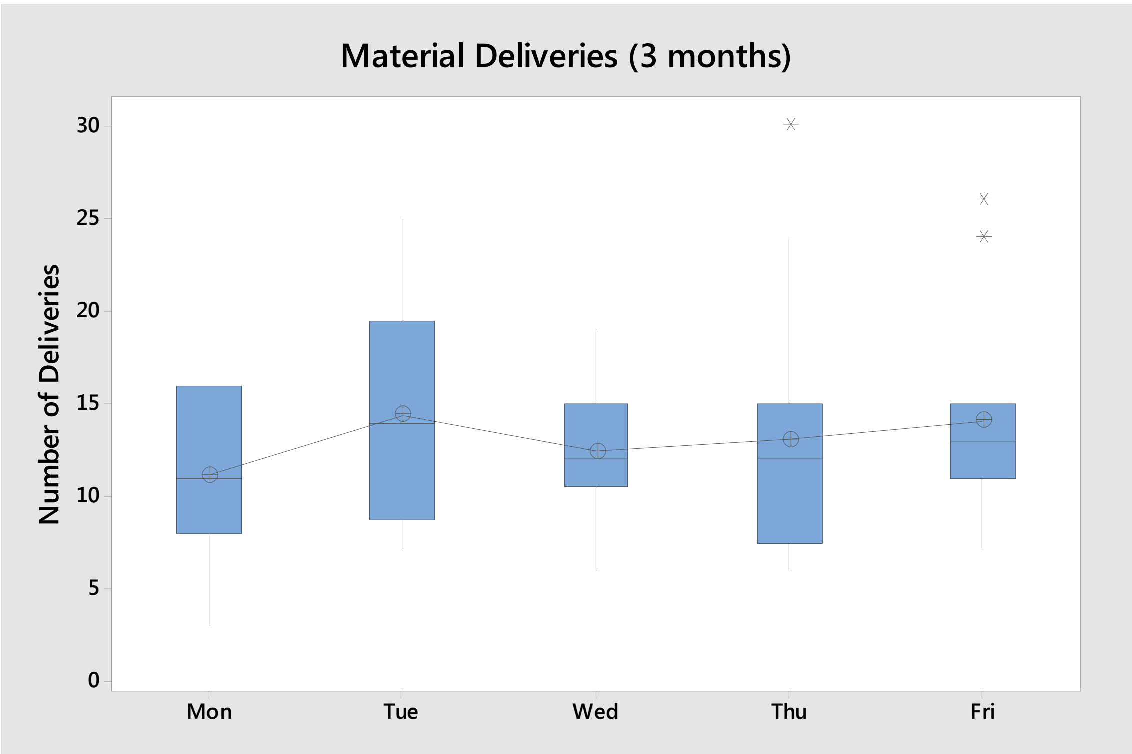
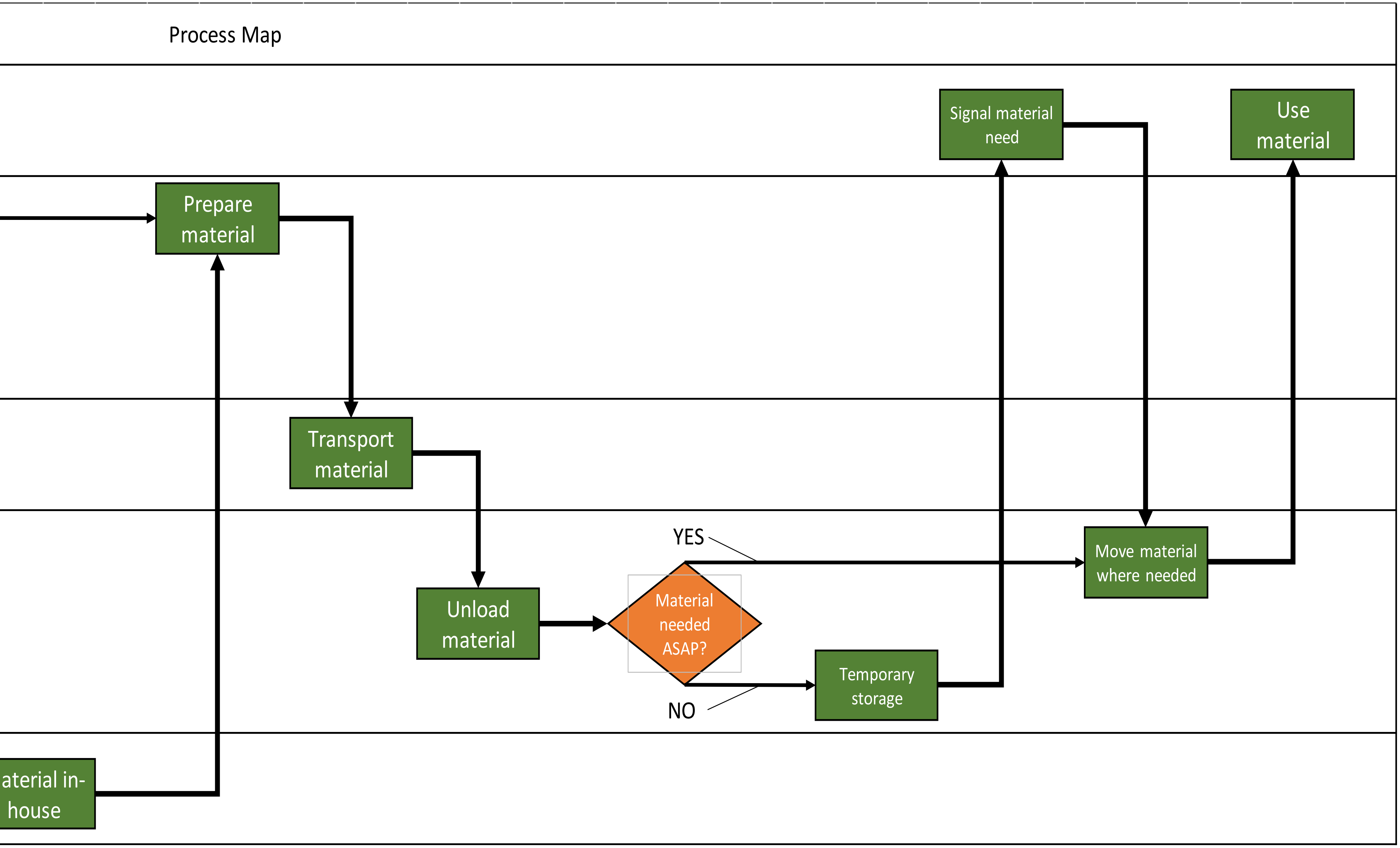



Figure 7. Boxplot analysis for material deliveries vs. days of the week.

After measuring the current performance of the process, a deployment diagram was made. The deployment diagram shows what each individual worker does in each process step. The diagram can be seen in Figure 8. The diagram makes it easier to understand what happens during the process, and what kind of different roles there are. Other process maps of current processes were also made: the current process for sending material in the logistics facility, and the process of receiving material in the factory. For these process maps, the individual performing the task was also included.

As a result of interviewing the workers, as well as measuring and creating process maps, several potential root causes were found. These were: ordering too much material compared to the actual need of production; ordering materials too late; materials received from suppliers might take a lot of time in logistics facility; the lack of material tracking; and the lack of material inspection in logistics, among others. These potential causes were noticed during the steps made before in the measure phase, and some came up after brainstorming potential problems. As suggested by the literacy, all of the potential root causes needed to be analysed further, in order to be able to focus on and remove the real root causes.


Process Map
Prepare material
Transport material
Unload material
Material needed ASAP?
YES
NO
Temporary storage
Signal material need
Move material where needed
Use material
aterial in-house

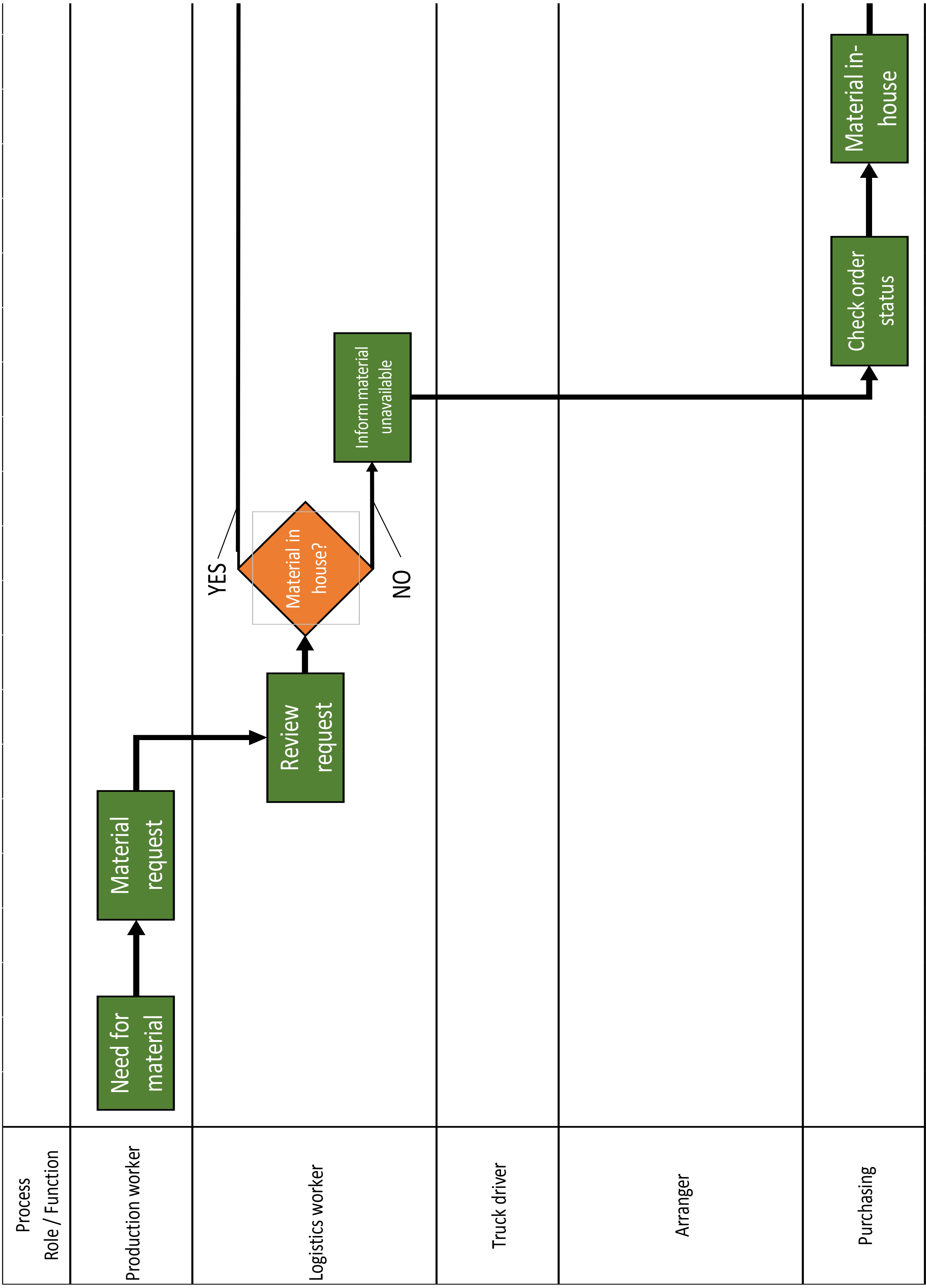



Figure 8. Deployment Diagram of material flow process.

## 1.5 Analyse phase

During the analyse phase, the potential root causes revealed in the measure phase were investigated further to reveal the most influential ones. To reveal the actual root causes from other possible ones, more in-depth analyses needed to be performed. In these analyses, the material orders of different production teams and assembly lines were compared to find reasons for delays.

A Pareto chart was created for analysing the three-day measurement done in logistics. As it can be seen from Figure 9, there were some specific tasks that required most of the time. In addition, a lot of time was spent waiting because there was nothing to do. It is worth mentioning, however, that no observation of any sort of laziness was made. Moments of waiting were due to the infrequent and unstable flow of material orders which caused time periods where there was no work available to be done. On the other hand, the unstable flow of material orders caused a lot of spikes in the amount of orders which resulted in late deliveries and very many unnecessary urgent deliveries.

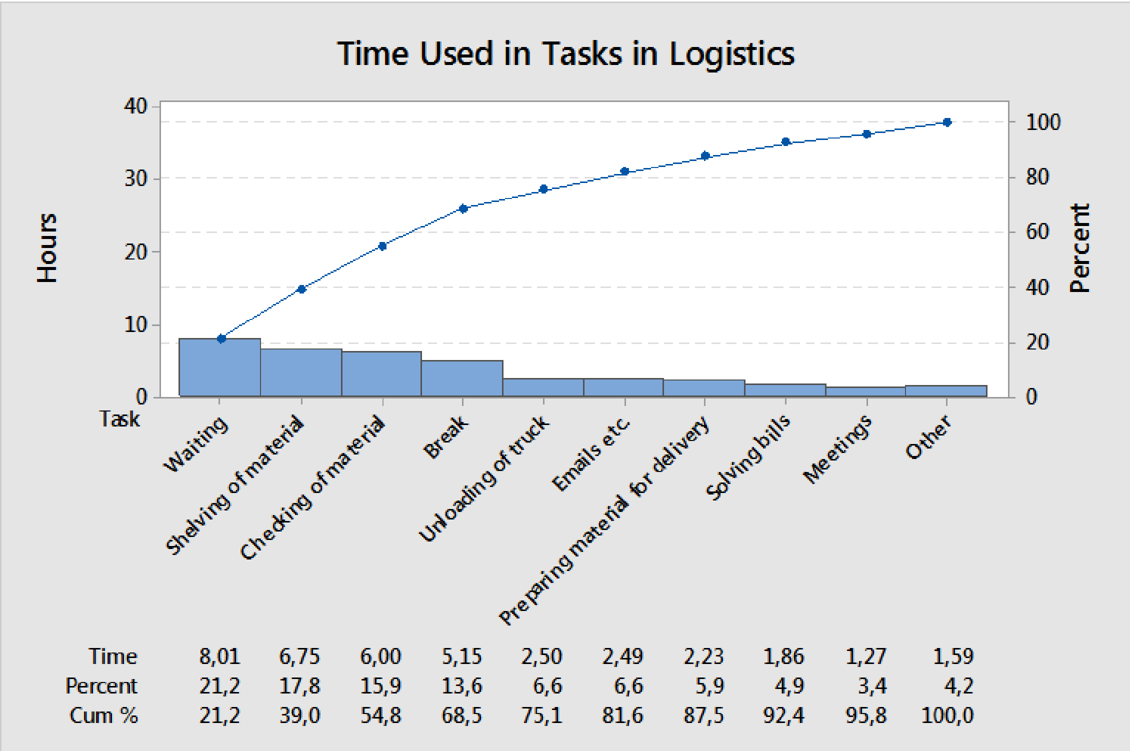



Figure 9. Pareto chart of time usage in logistics during a three-day study.

One root cause for the unstable material flow was revealed by analysing the process of ordering material to the factory. It appeared that workers were ordering too much material for a certain moment. The amount of material ordered for that moment was beyond the actual need for production. In addition, the work was not properly scheduled. The workers did not always have a clear vision of which work to perform next. Instead, they might have jumped from project to another, before finishing the project at hand.

Another issue which caused a lot of problems and waste in the factory was the intermediate storaging when a material was ordered to the factory too much in advance. There was no way to monitor the material flow inside the factory. Often this resulted in at least one worker waiting and looking for the material. This caused a lot of waste, mainly unnecessary motion and waiting. The root cause of the problem is the inappropriate ordering, but also the lack of material monitoring system. Material tracking is also needed when production shifts. For example, if a transformer fails its factory acceptance test and needs to be repaired, it will move back to the production. This will interrupt the on-going production and introduces a risk of material to go missing because of the hazzle in the production cell.

Another potential problem in the material order process was the large amount of last-minute orders. The last-minute orders brought several problems of which the most challenging was the change in the scheduling of logistics. When an order was made with only a little bit of time left to complete it in time, the logistics had to delay some other order. Because of this the delivery of the delayed order was often late and created a lot of waste. However, the last-minute order was often so important that it had to be expedited. Based on the analysis, it seemed that the amount of the last-minute orders had to be decreased.

Moving from the material ordering process to the material reception process in the logistics, two potential causes were introduced in the measure phase: the lack of material inspections; and the timing of deliveries from suppliers. The lack of material inspections caused several problems in production. These problems were due to an incorrect amount of material or damaged material in the delivery to production. Sometimes this caused serious delays in the production since materials had to be ordered again from the supplier. The analysis proposed that inspection of materials should be introduced in the logistics facility so that the defects would never end up in production. Inspections itself are waste, but the amount of waste increases by a vast amount if a defect reaches production.

The second potential problem in the logistics facility was the amount and timing of deliveries to the logistics facility from suppliers. The potential problem was that if there are some specific times when a large amount of deliveries is made, the workers in logistics could not handle the deliveries and the material orders. However, by analysing the amount and the timing of deliveries, both hourly and daily, there was no specific time or day found where there would have been a peak in the amount of deliveries. Thus, this potential cause was ruled out.

Based on the analyses, the following wastes were found in the processes: waiting, rework, unnecessary inventory, and unnecessary transportation. The analyses indicated that these wastes appear mostly because of the incorrect method of ordering materials from the factory, the lack of material monitoring, and the lack of material inspections. The deliveries from suppliers did not appear to have any effect on the late material deliveries to the factory from the logistics facility. As a result, improvements were needed to enhance the material order process in the factory and the material delivery process in the logistics.

## 1.6 Improve phase

After the analyse phase the next step in the project was to decide how to improve the processes that caused problems. The options for improvements were brainstormed with a focus on them being easy and relatively quick to develop. The brainstorming resulted in various separate improvements. Creating better instructions to the workers for ordering materials so that they are easy to understand, introducing material inspections to logistics process, improve the scheduling of production, and to create a material tracking system. Although all of the improvements are important and should be made, only the instructions for material orders and the material tracking system were chosen to be in scope for this lean six sigma project. Other improvements would need to be carried out in their own projects. Due to the limited time of this project, it was only possible to create suggestions and some preliminary actions during the project.

The improvement for the ordering process was necessary to stabilise the material flow. Stabilising the material flow was found to be an important factor in reducing the number of late deliveries. To tackle this problem, instructions on how to properly use and schedule the material orders were suggested. If done correctly, a week’s worth of materials for a certain project could be ordered with only one order, in under 15 minutes, and be scheduled correctly without wasting space and time of workers. The instructions had to be different for each part of the production process. This was because the different parts ordered materials in a specific order that was not the same as others. The proposed instructions were made as simple as possible and had pictures of the ordering software as an example. These instructions would be used to teach workers and to act as a rule book for material orders.

Another problem to be fixed was the monitoring of the materials. There already was a system to track materials in the logistics facility, but it never had been introduced to the factory. It was decided that it should be introduced, and the arrangers and workers should be taught to use it. However, a delay occurred before the improvement could be completed. The tracking software requires an internet connection to operate, and the laptops that use the software had to be mobile, ideally attached to the trucks that are used by the arrangers. However, there was no WLAN in the factory’s production areas at that time. Therefore, before the tracking software could be introduced, WLAN hotspots had to be installed to the factory. During this project, the places for hotspots were decided and the hardware was ordered. Even though there was no WLAN available, it was possible to make some preliminary design of the to-be process. The storage locations that would be added to the software were decided and named so that it was easy to navigate to each one in the factory. A map of the different storage locations was made, and the process of adding these locations to the software was started. Also, a process map for the desired process was created.

Both of the proposed fixes are easy and fast to implement. This kind of an improvement is called *kaizen* in lean terms. The process, however, will probably need some fine-tuning in the future to ensure that the process is up-to-date. Therefore, it will be necessary to follow the performance of the process based on the data constantly. The challenge will be to get the people in production to act by the process and making it a permanent change. To make a permanent change implementing continuous improvement through consistent reviews of the process performance will be required.

## 1.7 Control phase

The control phase is important for various reasons. In the control phase, a control plan is made to help sustain the improvements. With the control plan, it is possible to see changes in the process and to improve it further. In addition, the financial benefits are tracked for a period of time in the control phase. In this case study, the control plan included a measurement plan for the new standard process, the specification limits for the new process, a method for measuring the benefits, and an action plan in case of possible problems.

The first improvement suggestion to control the material flow was a meter that is to be reviewed monthly or weekly. This meter was an I-MR chart of the number of deliveries during each day of the past month where the number of deliveries is to be compared to the previous weeks. If the number of deliveries remains stable, the process is running as it should. However, if there is a lot of peaks, there might be a problem in the process and the reason for this needs to be investigated and solved. If the problem is not fixed, the unstableness causes problems in the logistics which causes late deliveries. One thing to keep in mind is that at times, the number of deliveries per day might change due to a change in production volume.

The second suggestion focused on improving the process measurement system. Instead of measuring the whole production department, more detailed measurements were needed. The suggested improvement was to gather data in a specific production unit instead of the whole department. This would make it possible to see which unit has the best performance, and which unit has room for improvement. This requires the workers to identify themselves more accurately so that it would be possible to see from Kotiinkutsu, which unit had made the material order. This change was introduced in the new instructions created during the project. The units can be identified by using the names of the workers or using a specific ordering name for each machine.

At the time of this project, there was no material tracking system in the factory which meant that there was no database or system to indicate missing materials. Therefore, the proposed method for measuring the process is to gather feedback from arrangers. When an arranger reports an incident of missing material or material in an incorrect location, action must be taken to investigate the reason and to correct it. It was suggested that in the future, the factory would start to use the same tracking system used in logistics facility. Some initial designing towards this system was done during this project. Material tracking was seen as an important factor because if materials are missing waste is created because of unnecessary motion and time wasted searching for the correct materials. In an ideal case, where the materials are delivered just-in-time for the immediate use in production, this would not cause a problem because there would not be a need for intermediate storage.

Finally, a plan was created to track the financial benefits of the improvement. This was possible by analysing the data from Kotiinkutsu. From the data it was possible to see for how many hours an item had been late. This was done by looking at the deliveries that were late and comparing their requested times with the times when they were actually delivered to the factory. The difference in these times indicated the total time the item had been late. This time difference was then multiplied by the cost of a worker or workers waiting for that item. With this formula, it was revealed that in the year 2017, a total of 485,000€ was wasted in this process, and this was an optimistic estimation where only one worker was estimated to be waiting for material.

# DISCUSSION

The objective of this study was to improve the process of internal logistics and material flow. The problem was a large number of late deliveries to the factory from the logistics facility. This problem was to be solved by using the methods of lean six sigma in a real-life project and with ideas and techniques based on the literature review. The supporting research questions were:

1. How to apply a DMAIC project in a real-life situation?
2. Can a lean six sigma project be used to improve a service process?

To answer the first question, a comprehensive explanation was made about how a DMAIC project and lean six sigma methods were used in the real-life improvement project. The second research question was answered mainly based on the literature review. This was because there was not enough time to implement the suggested improvements during the project. Therefore, the actual benefits of the improvement will remain to be seen.

This study began with a review of the current literature. Most of the literature reviewed were publications from scientific journals that were cross-referenced and had a minimum of 11 citations. However, most of the publications had over 40 citations and were not older than ten years, but there are a couple of older ones as well. A small number of popular books were also selected as there were a lot of citations in the journal publications based on these books. Therefore, the quality of the material for the literature review is trustworthy but could be expanded for further research.

After the literature review, a real-life improvement project that lasted for three and a half months was attended. During this project, the situation was studied and analysed using lean six sigma methods and the project made an attempt to follow the DMAIC cycle. In the project, DMAIC was not followed as rigorously as was suggested in the literature. For example, a project team was never formally assigned. However, it was possible to apply the many tools of lean six sigma and to find the root causes and to create suggestions for improvement. During the project, it was explained what kind of tools were used to solve the problems in the different phases of the DMAIC cycle.

Finally after various analyses, suggestions were made for the company to carry on improving the process.

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