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Productivity improvement as a facilitator of reshoring and growth at small companies

A case study in the Swedish electronics manufacturing industry

Master's thesis in Production Engineering

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SUMMARY

The Swedish electronics manufacturing industry has faced significant competition from countries with lower labour costs, resulting in production being relocated. However, at some companies, there is a growing interest to bring back production to the country of the company. To remain competitive, companies need to constantly improve productivity. At the luminaire manufacturer in this case study, having more production in Sweden would make it easier to fulfil customer demands, but the cost of producing locally is currently too high to make it feasible. Therefore, this thesis aims to investigate the potentials for improving the productivity at the company.

The first part of the thesis was investigating if insights could be gained from the data in the surface mounting technology (SMT) production. Then, the second part was understanding the current situation in the luminaire assembly and suggest improvement. A combination of qualitative and quantitative methods was used to achieve this. Interviews and observations, including participation, were used to gain an understanding of the products, material flows and work processes. Then, machine data, ERP data and time studies allowed the theoretical and actual production times to be analysed, allowing productivity improvement potentials to be found.

In the SMT production, data was found for theoretical and actual cycle times. By comparing these, key performance indicators (KPI) like availability and performance could be determined. This indicates that a better system for handling the data could be very valuable. In the assembly, many potentials for improvement were found. The proposal still includes pre-production in China, but all units of the product in the case are to be finished in Sweden. Then, the material flows could be changed with, among other things, a kanban system. Finally, by moving tools and materials closer to the operator at the assembly station, as well as providing them with support and standardization, the time for assembling the product could decrease by 30-50%.

Keywords: Productivity, Manual assembly, Material flow, Improvements, Sequential activity and methods analysis (SAM), Work design

List of Acronyms

CODP	Customer order decoupling point
FWAL	Fixed worker assembly line
KPI	Key performance indicator
MTM	Methods time measurement
OEE	Overall equipment effectiveness
PCB	Printed circuit board
PCBA	Printed circuit board assembly
PMTS	Predetermined motion time system
SAM	Sequential activity and methods analysis
SMT	Surface mount technology
WIP	Work in process
WWAL	Walking worker assembly line

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1 Introduction

Electronics manufacturing is an industry where some companies might grow rapidly while others are forced shut down. For smaller companies, acquisition of other companies could be used as a strategy for growth (Li et al., 2011). However, small companies do not have the same access to funding for investments as larger companies do (Eldridge et al., 2021), limiting the possibilities of this strategy. Therefore, improving the profitability of the operation could be a key part of growing the company (Zhai et al., 2007). Sundkvist et al. (2012) have shown that there often is a great potential for improvement in the Swedish electronics manufacturing industry, where resource utilization is an important problem. These companies currently cannot produce at the low costs that eastern European and Asian companies can (Sundkvist et al., 2012), something that historically has led to production being moved away from Sweden.

The relocation of manufacturing operations to foreign countries, known as offshoring, was a large trend starting in the 1990s (Longauer et al., 2023). By 2014, more than half of Swedish manufacturing companies had offshored as shown in Figure 1 (Baum et al., 2022). At the time, companies did not consider manufacturing as a core competency, and offshoring therefore emerged as a strategy to reduce manufacturing costs (Hartman et al., 2017). However, since roughly the late 2010s, the interest in offshoring has declined. Wages are increasing in some of the countries that used to have low labour costs (Unterberger & Müller, 2021). International crises like the covid-19 pandemic and the war in Ukraine have shown that the global and complex supply chains created after offshoring are less resilient. Companies have also been facing problems with quality and reverse engineering (Longauer et al., 2023).

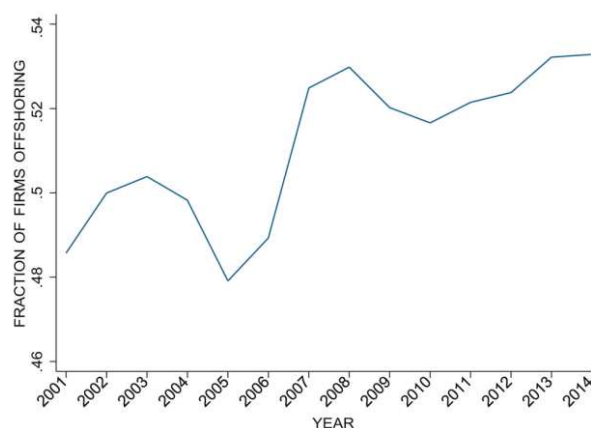


Figure 1. Offshoring prevalence at Swedish manufacturing companies (Baum et al., 2022)

The risks associated with offshoring have given rise to an opposite trend, reshoring, where companies move their manufacturing operations back to their country of origin (Bilbao-Ubillos et al., 2023). Having in-house manufacturing allows organizations to gain knowledge from learning-by-doing, for example, within the area of productivity. Having companies both design and manufacture products is also beneficial for innovation (Longauer et al., 2023). Longauer et al. (2023) argue that reshoring can

reduce manufacturing costs in the long run, under the assumption that productivity is increased by having in-house manufacturing and cannot ever be decreased. However, the companies in the study by Sundkvist et al. (2012) are already operating their own manufacturing and possibly have been for some time. As they still have very clear potentials for improvement, it allows the findings by Longauer et al. (2023) to be questioned. With this perspective, productivity starts appearing as a barrier for reshoring, perhaps a key part of the cost difference between manufacturing in Sweden and countries like China.

These productivity improvements could still come at a cost though, requiring an investment. One such example could be purchasing better tools and machines (Almström & Kinnander, 2011). However, many approaches to making investment decisions include comparing the cost of the investment to the benefits (Ekanem & Smallbone, 2007), something that is quite complex for some types of manufacturing investments (Bhatia & Diaz-Elsayed, 2023). Quantifying the value of the productivity investments thereby becomes yet another barrier to achieving reshoring. Fortunately, it is possible to compare the productivity of different production systems without having to use advanced mathematical models, which could be very useful at smaller companies.

1.1 Background

The studied company is a Swedish luminaire manufacturer with sites in Sweden as well as in China. The manufacturing operation in Sweden has a surface mount technology (SMT) line which manufactures printed circuit board assemblies (PCBA), with accompanying post-processing and testing. The site also has an assembly area for producing complete luminaires, also with its own testing. By having manufacturing sites in both Sweden and China, they can choose to manufacture their products in either site based on what they find most suitable. It is also possible to manufacture assemblies in China that are finished in Sweden, something that is quite common for certain products at the company. However, production in China results in lead times of up to approximately 20 weeks when accounting for material procurement, production and transportation. Meanwhile, the market often wants their products within 1–2 weeks. This creates a conflict between production cost, delivery performance, flexibility and tied up capital. Forecasting inaccuracies may also lead to reworks when customers order variants different from those that were prepared in China, where products are taken apart and assembled according to the new specification.

A potential solution for the assembly problem is to relocate production to Sweden, in which case the lead time would likely no longer be an issue. However, the final assembly in Sweden is significantly more expensive than that in China. This limits the company's ability to relocate manufacturing to Sweden, despite the clear benefits in terms of shorter lead times and increased flexibility. For reshoring to be economically viable in this case, production-related costs must be significantly reduced. Currently, it is unknown to what extent the productivity can be improved and which changes in production layout, material flows, standardization, and organizational practices would be required to achieve it.

In addition, it is unclear what type of data exists in the SMT production and how the data could be used to support improvements in making the production more efficient. There is no established way of measuring production times and disturbances at the company, meaning that the current potentials for improvement are unknown.

1.2 Aim

The aim of this thesis is to investigate how the productivity within the Swedish operations of the case company could be improved to support more efficient local production, allowing more production to be performed in Sweden rather than China. The thesis focuses on two separate parts of the operation: the SMT production and the final manual assembly.

The first part of the study aims to analyse available production data from the pick-and-place machine in the SMT process and identify what insights that can be gained regarding the current machine performance and utilization. This can in turn provide a basis for future improvements, allowing the utilization of the existing machine to be improved.

The second part of the study focuses on the final manual assembly operation of a particular luminaire product family, Alpha. This part aims to examine the current state of production including material flows, workstation organization, layout and assembly work methods to identify losses and inefficiencies. Based on the current state, the study then further aims to suggest improvement opportunities that can in turn reduce assembly-related costs and support a more efficient assembly operation.

1.3 Delimitations

The scope of this research project is limited to analysing the SMT process and the final assembly operation within the Swedish production facility. The purpose is to analyse the current situation and suggest improvement opportunities, but implementation of the proposed improvements is outside of the scope of the project. The study will mainly utilize traditional industrial management tools and methods, such as Microsoft Excel for quantitative data analysis. There will not be any advanced programming or mathematical models, meaning that the result is not an optimization but instead a more qualitative range of improvements.

The final assembly part of the study is limited to the Alpha product family within the Swedish production operations and doesn't include a detailed analysis of manufacturing processes carried out in China. The study, therefore, focuses on analysing and improving the existing operation within the Swedish production facility. However, discussing how the products from China are packaged and presented to the workers in Sweden could be possible due to it being a more operational matter. Alpha is a new product that is expected to remain for a longer period and is therefore considered relevant for production improvements and even possible future production developments. The study focuses on operational perspectives such as production strategy, layouts, material flows and working

methods, while product design and technical product development are excluded from the research project.

The delimitations within the SMT operation will have a process perspective. The pick and place machine in the SMT line constitutes the biggest investment, and this machine is therefore the most desirable subject for efficiency improvements. As the products have varying volumes, the project will only be able to cover a selection of those that are in production around the data collection phase of the project. Using too old production orders or products that haven't been manufactured recently could decrease the value of the result.

1.4 Research questions

To achieve the aim of the thesis, one question for the SMT production and two questions for the assembly operation were developed.

RQ1: What data is available from the SMT process, and what insights can be gained from it?

RQ2: How does material currently flow within the final assembly, and how is the assembly work organized?

RQ3: What improvement opportunities could be identified to make the final assembly more efficient?

Research question one (RQ1) focuses on analysing the availability and usability of production data from the pick-and-place machine in the SMT process. For example, the concept Overall Equipment Effectiveness (OEE) could be used as a tool to interpret the collected production data and identify potentials for improvement.

Research questions two (RQ2) and three (RQ3) focus on analysing the final assembly. RQ2 aims to analyse the material flow and the assembly work in the final assembly to understand what the current situation looks like in terms of production approach, material flows, workstation design and assembly processes. By using this information, the third question aims to propose improvements that can reduce the assembly times.

2 Theoretical framework

This section is divided into five subsections, each covering a different aspect of literature. The first subsection introduces the productivity frameworks for manual and automated work that will be key parts of the quantitative analysis. Then, the following subsections include other principles for designing efficient manufacturing operations.

2.1 Productivity

Productivity is the relationship between the outputs and inputs (Almström & Kinnander, 2011), how much value can be created with a given amount of resources (Heragu, 2023). On a national level, higher productivity means higher living standards. It increases the value of goods created, which also has the potential of improving labour compensation (Antonakakis et al., 2025). On a company level, productivity is an important competitive factor as it influences the profit margins (Almström & Kinnander, 2011). When there is strong competition in the market, companies are forced to keep improving their productivity (Wen et al., 2025).

While a generic analysis of productivity might consider the financial inputs and outputs, it could also be analysed on an operations level with the metrics method, performance and utilization (Heragu, 2023). Method is the ideal production rate when working at a normal speed, which could be decided by a predetermined time system. This is described as the most important factor for improvement, as better tools and machines can have a large impact on the ideal production rate. Next, performance is the speed at which the work is performed, how the actual speed relates to the normal speed. Finally, utilization is how much time is spent on the intended work, showing if time is lost on things like breakdowns and set-ups (Almström & Kinnander, 2011).

Increasing the level of detail even more, performance can be divided into personal, the effort that the worker puts into the work, and skill based, how trained the worker is for the task. Meanwhile, utilization can be divided into need based, which includes breaks and recovery, system design, losses coming from the design of the production system, and finally disturbance affected, which encompasses the losses coming from random disturbances. Multiplying these factors, in total 6, allows the productivity improvement at an activity level to be determined, allowing different productivities to be compared (Almström, 2013). The equations are shown in the Appendix.

While some authors make it appear as if there is consensus on measuring productivity through method, performance and utilization, companies often use their own definitions. In addition, governments could also have their own definitions of productivity. Even within a company, there could be different perceptions of productivity on the operational, tactical and strategic levels, making the situation even more complicated (Clegg et al., 2025). This thesis, however, considers productivity through the previously mentioned three dimensions method, performance and utilization. By calculating it this way, productivity improvements can be measured on a suitable scale for the research project.

2.1.1 Predetermined time systems and MTM-SAM

Work design is the structure of the work that employees perform. This has an impact on the well-being of workers and the efficiency of their work (Oldham & Fried, 2016). One approach to designing work is methods engineering, which consists of

identifying what operation to design, analysing and measuring the work, designing an improved work method, implementing it and finally sustaining it. When measuring work, an important factor is time. With time studies or predetermined time systems, standard times can be calculated that allow different methods to be compared (Kelly, 2023). When an efficient way of working becomes the standard, productivity could be improved, not only because of the new method but also through improved utilization and to some extent performance (Mor et al., 2019).

Standardized work refers to determining and documenting the most efficient and repeatable way to perform a task (Mor et al., 2019). This aims to reduce process variations and improve operational performance. According to Mor et al. (2019), standardized work creates a basis for continuous improvement, reduces non-value-adding activities while contributing to clear work sequences and procedures, which may also support the transfer of knowledge and methods between operators. Mattsson et al. (2020) argue that operators in modern assembly systems perform tasks of varying complexity and therefore need information support based on the work situation. Information support and instructions should support operators' cognitive processes and aim to facilitate assembly work, which Mattsson et al. (2020) further explains should be adapted to operators' knowledge level and assigned tasks.

Predetermined time systems, also known as predetermined motion time systems (PMTS), consist of predetermined times for basic motions (Assef et al., 2018). By defining which basic motions are performed in an operation, the theoretical time for the operation could be calculated (O'Leary, 2023). To create a more practical standard time, allowances are added to the theoretical times to account for the needs of the workers. This addition could be 10%, but also other values based on the situation. Once this is done, the standard times are ready to be used by operations managers (Karim et al., 2016). Compared to looking at historical data, a PMTS will generate more consistent standards since they determine how long the work should take regardless of how long it usually takes (Hedman & Almström, 2017).

Methods time measurement (MTM) is a methodology that was initially published in the 1940s and became a popular tool to determine standard times. The first MTM PMTS known as MTM-1 was followed by MTM-2, MTM-3 and ultimately many other systems (Karim et al., 2016). Sequential activity and methods analysis (SAM or MTM-SAM) was developed in Sweden in 1982, in collaboration with companies and unions. It was designed as an improvement over both the second and third versions of MTM, attempting to balance the speed and accuracy of the analysis (Turunen & Almström, 2024). The system is less detailed than other ones, but also faster to use. For example, analysing work with MTM-1 takes roughly 200 times the length of the work, while analysing it with MTM-SAM takes roughly 25 times the length of it (Hedman & Almström, 2017). Trials showed that SAM does not have any significant systematic error and that it is faster to use than all other non-proprietary MTM-based systems (Turunen & Almström, 2024).

The analysis uses a form where the work is divided in rows. Each row consists of the sequences get, put, use and return, each of which have many options for how to describe the activity. Get and put are the most basic activities, divided into three distance classes and with a few additional options. Use contains repetitive activities like screw, crank and hammer with many different variants available. Finally, there

are three supplementary activities scattered across the row: Step, bend and apply force (Turunen & Almström, 2024). Ultimately, the times generated from the analysis are based on what work method the analysis considers. When performing the analysis, value adding and non-value adding motions can be identified, allowing the method to be improved. Common losses include taking too many steps, bending the body, turning the body, picking and placing things too far from the body as well as various losses coming from the design of the production system, including layout and flow (Turunen & Almström, 2024).

2.1.2 Overall equipment effectiveness

To determine the efficiency of machines, the key performance indicator (KPI) overall equipment effectiveness (OEE) can be used (Almström & Kinnander, 2011). This metric includes availability, performance and quality aspects in the form of percentage values, capturing different kinds of losses. By multiplying these, the OEE is calculated as a percentage value that reflects all losses (Hung et al., 2022). While OEE is a very important metric when measuring individual machines, Braglia et al. (2008) argue that it does not capture the losses of more complex production systems. The KPI also focuses on the machine itself, not properly accounting for external factors such as labour (Braglia et al., 2021).

Availability is the relationship between operating time and loading time, which includes downtime losses like stops and setups. Performance is the relationship between the theoretical time and the operating time to produce a certain number of units, which includes speed losses like micro stops and operating at reduced speeds. Finally, quality is the relationship between the number of approved units and total production, which includes defect losses (Muchiri & Pintelon, 2008). These different losses are all shown in figure 2, and the equations used to calculate the OEE are available in the Appendix.

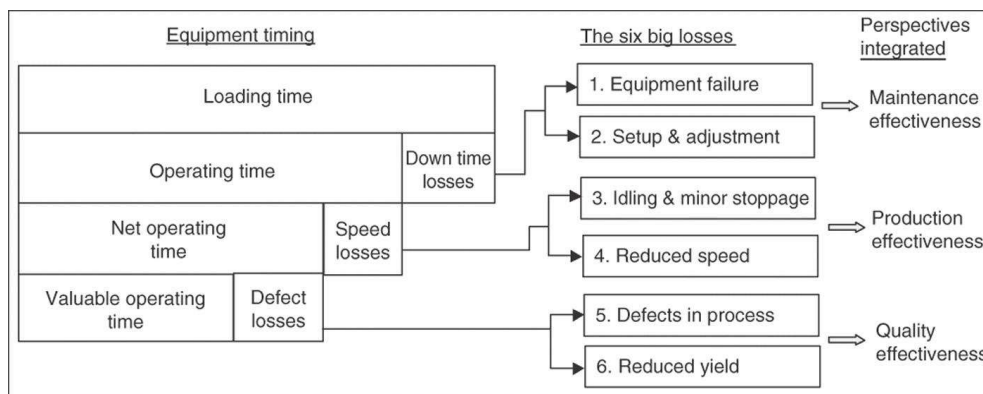


Figure 2. The six most important types of losses in the OEE (Muchiri & Pintelon, 2008).

Micro stops could be defined as stops shorter than a few minutes, and possibly also as occurring frequently (Zennaro et al., 2018). These stops are hard to measure and could in some cases influence other factors than performance (Ylipää et al., 2017). No precise definition appears to exist in literature, which might force each company to define their own threshold between micro stops and longer stops. Meanwhile, setups could be defined as the processes of preparing resources for performing a task (Allahverdi & Soroush, 2008). For bottleneck machines, setup times limit the

efficiency of the entire production system (Almomani et al., 2013). In situations where production batches are small, it is important for setups to be short (Zhang et al., 2023), as too much time would otherwise be spent on preparation rather than production. The time required for setups could depend on the specific sequence of products (Vallada & Ruiz, 2011), meaning that improvements in the planning of production could result in lower setup times. According to Almomani et al. (2013), reducing setup times is a foundation for effectively implementing lean production principles.

To create an OEE system, some decisions must be made. First, the OEE must be thoroughly defined, including all components. Then, the system must be implemented by collecting the right data from information systems and preparing it for analysis. Finally, once the calculations have been made, the users of the system must understand how it works to make the proper decisions (Kechaou et al., 2022). The challenges regarding data are important, as good data is required to create an accurate OEE. Classification of stops enhances the decision-making support that the system provides, but this is often lacking. To make this possible, loss categories must be defined in such a way that the people making the decisions in the company can understand and address common problems (Hedman et al., 2016). On a lower level, the raw data from the machines might sometimes be in a format that does not immediately allow events in the machine to be understood and used for calculation. In this case, the data must be transformed into the right format using software (Farooqui et al., 2020).

In the Swedish electronics manufacturing industry, the utilization of machines and thereby availability is described as having the largest potential for improvement. This issue is thought to exist in other countries with high labour costs as well, as companies in these environments often prioritize factors like flexibility over cost (Sundkvist et al., 2012). These kinds of losses may not only come from the machines themselves but could also arise from many other sources inside and outside the company. One possible issue is logistics, both external and internal, where there could be issues in the supply of resources required for the operation, or in the delivery of finished goods. In these cases, the production might have to shut down temporarily because of these disruptions (Muchiri & Pintelon, 2008).

2.2 Manufacturing strategy and material flows

On a larger scale, any operation can be modelled as an input-transformation-output process. The inputs are transformed resources, which become products, and transforming resources, which perform work upon the transformed resources, both directly and indirectly. The transformation process combines these two types of resources into an output, which in the case of the manufacturing industry are products. Inside the operation, there is a hierarchy of processes, where operations have sub-processes with their own internal suppliers and customers. Each of these are part of are part of different flows, interacting with other processes and forming a system (Slack et al., 2022).

According to Harfeldt-Berg and Ohlager (2024), the customer order decoupling point (CODP) represents a strategic variable that refers to the point in the production and supply chain where a product is linked to a specific order, separating forecast-driven

activities (make-to-stock) from order-driven activities (make-to-order). The location of the CODP determines when final production or assembly should take place and reflects the trade-off between achieving physical efficiency through large-scale production (make-to-stock) and offering high flexibility and customer customization through order-driven operations (make-to-order). Harfeldt-Berg and Ohlager (2024) show that a make-to-stock strategy is most suitable for environments where low demand uncertainty exists, where variation is low and volume is high, where standardized products can be manufactured in advance to be cost-effective and have low lead times. However, Harfeldt-Berg and Ohlager (2024) argue that this strategy is based on accurate forecasts that can lead to inefficiency in the event of unpredictable demand. In contrast, make-to-order is an approach more suitable for contexts with higher demand uncertainty and variability, lower volume, where production is postponed until customer requirements are known, increasing flexibility but typically resulting in longer lead times. Harfeldt-Berg and Ohlager (2024) also highlight an intermediate strategy, assembly-to-order, where components or modules are produced and stocked in advance, while the final assembly is postponed until the customer order has been received. In this method, CODP is positioned between component production and final assembly, allowing companies to maintain a certain efficiency with pre-produced components, while achieving responsiveness without making delivery times too long by adapting the final product based on actual customer demand. This view is supported by Lua et al. (2007), who argue that modular product design enables firms to delay product differentiation until later stages in the supply chain. Both Harfeldt-Berg and Ohlager (2024) and Lau et al (2007) highlight that postponing final assembly reduces the risk of producing incorrect variants and improves responsiveness to customer demand. On the other side, make-to-order and assembly-to-order can increase lead times compared to make-to-stock. Companies need to match the CODP position and the production strategy to the demand characteristics and find a balance between efficient production and flexibility (Harfeldt-Berg & Ohlager, 2024).

In a spectrum with process variety ranging from high to low, and process volume simultaneously ranging from low to high, the processes in operations can be divided into 5 types: project processes, jobbing processes, batch processes, mass processes and continuous processes (Petropoulos et al., 2026). In the case of manufacturing, jobbing, batch and mass processes might be the most common. Translating these into real factory layouts, jobbing and batch processes correspond to functional and cell layouts, while mass processes correspond to cell and line layouts (Slack et al., 2022). Functional layout (or process layout) is one end of the spectrum, where similar machines are grouped together. This makes the system flexible at the expense of difficult planning and material handling. In contrast, line layout (or product layout) groups different machines that are used for one or more specific products, placed in the sequence they are used. With a much simpler flow, planning and material handling becomes easier. Finally, cell layout is a combination of these two extremes (Hasan et al., 2012), which could be useful in cases where neither approach is perfect.

2.2.1 Production logistics

In a production logistics context, the flow of materials inside the factory becomes very important. These materials flow from the raw material and components

inventories towards value adding processes, where the material is considered as work in process (WIP) while value is being added to it. Between the processes, there may be stores of semi-finished items where items wait before proceeding through the flow. Finally, the material flows to the inventory of finished goods (Jonsson & Mattsson, 2009). There are many types of costs related to the material flows, and because of this, different roles in the organization can have different views on what to prioritize. One important source of cost is tied-up capital, which includes materials present at all stages of production. Another is capacity utilization, how much of the available production capacity is utilized. These are in conflict when it comes to the sizing of buffers (Jonsson & Mattsson, 2009).

Due to the stochastic nature of manufacturing, material flows could be disrupted (Xi et al., 2022). Stations might become starved, not getting the materials they need, or blocked, unable to move the processed materials. Buffers can mitigate these problems, resulting in a higher production throughput, but come at a cost (Petropoulos et al., 2026). Larger buffers result in more WIP and forces each product to spend a longer amount of time in the production system (Xi et al., 2022), resulting in an inventory cost. Additionally, buffers occupy space (Petropoulos et al., 2026) and require investments to be created (Xi et al., 2022). Therefore, improving the utilization often requires a higher tied-up capital, while reducing tied-up capital often results in a lower utilization. In theory, there should be an optimum point where the difference between the benefits and costs of the buffers is as large as possible, resulting in the highest possible profit (Jonsson & Mattsson, 2009).

Material handling, the process of moving any materials in the factory, generally generate high labour costs if performed manually. Therefore, it is important for any operation to reduce the distance that materials must be moved. The process and layout selection is one important area to work within, as it has a large impact on the material handling requirements (Petropoulos et al., 2026). In functional layouts, products take different paths in the production system, but it is possible to organize the operation in a way that minimizes the total distance the products are required to be moved. Meanwhile, cell and line layouts intrinsically require less material handling, which means that optimizing the material paths in detail is not necessarily required. If the cell or line has a high variety though, there might still be a high requirement of material handling (Petropoulos et al., 2026).

Workstations can be supplied with materials in different ways, where continuous supply is a conventional option (Hanson & Brolin, 2013). With this approach, complete pallets or boxes are delivered to the stations, which is useful for parts in high demand. Another option is boxed supply, where materials are repacked in smaller containers before being delivered (Simões et al., 2025). Kitting is a special way of supplying workstations with material, where the components needed for one cycle of work are grouped in a kit (Hanson & Brolin, 2013). This allows parts to be presented in a way that can reduce the assembler searching time, walking distance and material handling at the assembly station. On the other hand, it also introduces its own time and costs in terms of additional preparation, transportation and other handling activities related to preparing the kits (Hanson & Brolin, 2013).

Pull production is a method of controlling workload and a fundamental principle of lean production. In this type of production, upstream stations only supply downstream

stations once they demand it (Powell et al., 2013). Kanban is a pull-based system where materials and production are based on actual consumption and needs rather than forecasts or schedules (Huang & Kusiak, 1996). According to Huang and Kusiak (1996), the aim is to reduce inventory levels, improve productivity and deliver materials just-in-time to workstations. Kanet and Wells (2019) further describe that bin-Kanban systems are used for point-of-use inventory management where materials are stored close to the workstation and replenished when a container becomes empty. Point-of-use inventory systems can simplify replenishment activities and reduce handling complexity since materials are replenished only when needed and stored close to the workstation (Kanet & Wells, 2019). This approach is described as visual, simple and intuitive and further states that the system simplifies inventory management and material flows within production environments (Kanet & Wells, 2019). In addition, the authors highlight that the need for complex information systems and continuous inventory monitoring is reduced as bin-Kanban systems are more self-directed, in other words, the system signals to replenish when a box is empty (Kanet & Wells, 2019). Kanet and Wells (2019) highlight that kanban systems are well suited for frequently used and relatively low-cost components, as well as situations where many items need to be managed in a simple and visual way.

To achieve efficient material flows in manufacturing, Needy and Bidanda (2001) list some key principles: The product should always move forward, not going back and forth between parts of the factory; The flow should be as continuous as possible, reducing queue times and inventories of materials inside the factory; The disruptions should be minimized, as they increase the total time to manufacture a product; The flow should be flexible and modular, grouped under the term adaptable, where flexible means being able to switch between manufacturing different products quickly without disruptions, and modular means being able to produce at different volumes without altering the production system; The flow should be designed to improve the quality of products, with quality in mind at every step and not just in a final quality inspection; Finally, perhaps in contrast to creating continuous flows, the flow also has to account for the uncertainties that arise in manufacturing. To do this, buffers can be used. While this results in materials being stored throughout the operation, it also makes the flow smoother.

2.3 Manual assembly processes

Assembly is the process of combining parts into assemblies and products. The testing of these deliverables is usually done in connection with the assembly, allowing the combination of assembly and testing to be viewed as a system. While larger material flow issues can have clear impact on the assembly efficiency, there is usually a big potential for improvement within the assembly operation itself. Assemblers often spend time on many other things than purely assembling and testing, a problem which arises through the design of the work (Baudin, 2002).

Baudin (2002) lists 7 key types of waste in assembly: Overproduction, which can occur through a failure in the production planning, where workers have nothing to do but keep producing something which demand has already been fulfilled; Waiting, which will happen if there are supply chain issues. However, in situations where assemblers are working together, this can also be caused by imbalanced workloads,

which forces workers to wait for others to finish their task before being able to do their own task; Transportation, if material handlers are required to move parts between processes, especially short distances; Process, if the work is designed in a way that takes an unnecessary amount of time; Excess inventory, which for example allows operations to keep going in the event of disturbances, but results in too much tied-up capital; Motion, when workers do unnecessary motions such as walking a distance to pick parts as well as handling and orienting the workpiece; Finally, production of defectives, for example when making a failure in picking and labelling. To eliminate these types of wastes without an unnecessary amount of effort, there are methods which can be used to systematically design and operate assembly systems with reduced waste (Baudin, 2002).

Another important factor in manual assembly is ergonomics. This type of work could pose a risk to employees, for example through repetitive or strenuous tasks which result in musculoskeletal disorders and injuries. However, there is also an impact to the company across factors like productivity, quality and reliability (Botti et al., 2017). Therefore, if a company does not consider the ergonomics when designing the work, it might suffer various costs (Falck & Rosenqvist, 2014). Aside from improving the performance of the production, some researchers also argue that proper ergonomics could facilitate a successful adoption of lean practices (Sakthi Nagaraj & Jeyapaul, 2021). One important situation in assembly is the picking of components, where long reaches and bends are prevalent. Therefore, materials should be placed near the operator (Hanson et al., 2018).

2.3.1 Assembly lines

An assembly cell or line creates a clear flow of material that is more continuous, with one product at a time moving rather than batches, flowing in one direction with stations that are specially designed for each task. Two common barriers to choosing these layouts are that the volume is perceived as too low while the number of variants is perceived as too high. However, many processes across variants could be similar and repetitive, which therefore still allows a cell or line to be created. A third concern is that assembly line work negatively affect the well-being of workers, and this has always been relevant (Baudin, 2002). Therefore, the humans in the production systems must be considered when designing and improving it.

Bench assembly is a way to organize assembly for low volume and high flexibility with stand-alone benches where operators perform assembly operations from start to finish. In extreme cases, any bench and any operator can assemble any product, requiring all fixtures and tools to be available at every bench (Baudin, 2002). In an assembly line on the other hand, both workers and stations are specialized for their respective tasks. This means that operators initially only are required to learn one shorter cycle of work, and that each station only must be equipped with the fixtures and tools that specific work cycle needs. This type of assembly makes the flow easier, as materials take the same paths every time. The quality can also be improved because of the specialization. With these benefits, an assembly line is a way of improving the operation across more aspects than volume. According to Baudin (2002), an assembly line would be beneficial even if it only had one worker going between the stations and performing all work by themselves.

To create a line, or perhaps any type of manual assembly, the first step is to gather assembly times. This could be done with predetermined time systems or stopwatch and video time studies. With the data at hand, the entire assembly operation is broken down into a chosen number of stations, or to achieve a chosen cycle time (Baudin, 2002). To make a line efficient, assembly line balancing could be used. This process aims to assign work to stations in a way that maximizes production and minimizes cost (Boysen et al., 2022). To perform the balancing, the cycle times of all stations are collected, and tasks are then moved from those with higher times to those with lower times. The goal is to achieve cycle times that are all within 5% of the average cycle time (Baudin, 2002).

Depending on the variety of products made in an assembly line, the line is described as a single-model, mixed-model and multi-model (Petropoulos et al., 2026). A mixed-model assembly line can produce different product variants and still benefit from the efficient material flows that assembly lines have (Ebrahimi et al., 2022). Meanwhile, a multi-model line has larger differences between products which result in setups being required sometimes (Mezghani et al., 2024). When creating this kind of line, there are five important categories of resources to consider: Space, availability, cost, performance and people. The performance category in this case usually includes production ergonomics while the people category usually includes operator skills (Gianassi et al., 2025). Skills should reasonably be quite important if the operators are to produce different variants.

There are two key paradigms of staffing assembly lines: Fixed worker assembly line (FWAL) and walking worker assembly line (WWAL). FWAL means that each worker stays at a single workstation, which is considered as the traditional strategy. WWAL on the other hand is when workers move between the stations, which could mean following the product through the entire assembly line (Calzavara et al., 2025). The workers would in this case have to be trained to perform all tasks along the assembly line, but there are benefits that could outweigh this. Having walking workers is described as highly flexible, being able to change the output of the production system without redesigning and rebalancing the line. This makes WWAL systems suitable for situations where the customer demands are fluctuating (Catalano et al., 2025).

3 Methodology

This chapter describes the methodology that will be used during the research project, to answer the research questions and fulfil the aim of the project. First, the research approach is presented, which describes the overall structure of the study. Then, the workflow that will be followed throughout the study as well as the data collection and analysis methods are presented. Finally, the chapter concludes with the ethical aspects.

3.1 Research approach

This study will adopt a case study research design, which involves a detailed examination of a specific case in a bounded system (Voss et al., 2002). The case study is a well-used empirical research design and is suitable for investigating complex phenomena in the real-time context (Yin, 2018). That means that the phenomenon is studied in its real context and that the surrounding conditions such as people, structures, and work processes are retained. This is specifically important in this case where the surrounding conditions have a major impact and cannot be ignored. This case study methodology also allows for an iterative and flexible research process, which allows the possibility of evolving the study as new insights emerge (Bell et al., 2022). Since the project has an aim of investigating a specific production system in a real-world operational environment, the case study is considered appropriate research design.

Guided by the research questions and existing literature, qualitative and quantitative data were collected from the case company (Voss et al., 2002). The thesis deployed a qualitative case research method for its suitability to answering “why” and “how” questions (Voss et al., 2002). Data were collected from semi-structured interviews, direct participation and observations of actual production operations. The interviews were performed with managers, supervisors and operators within the production and the interviews lasted between 40 and 60 minutes. In addition, quantitative data from the ERP system were collected. This data source triangulation improves robustness and credibility of the findings (Yin, 2018). A more detailed discussion on data collection can be found in Section 3.3.

According to Bell et al. (2022), research can follow an inductive, deductive or abductive logic of inquiry. An inductive approach aims to develop new theories based on empirical observations. A deductive approach instead starts with existing theories and hypotheses that are tested empirically. An abductive approach focuses on an iterative process between theory and empirical evidence, which aims to identify explanations for observations linked to the phenomena. The research will follow an abductive approach, where empirical data from the case will be compared with existing theory. The literature spans operations and production management, particularly within areas such as lean management, material handling, productivity measurement, work design and assembly systems.

3.1.1 Work process

The work process for the study is visualized in Figure 3. The workflow is divided into different parts to visualize how the research projects were carried out and how the

research questions were addressed. The first step was to define the research project, its objectives and set a direction for the work. Then data collection, both quantitative and qualitative, began. In the meantime, related literature was also reviewed. This was done iteratively to enable in-depth analysis and adjustments based on emerging insights (Bell et al., 2022).

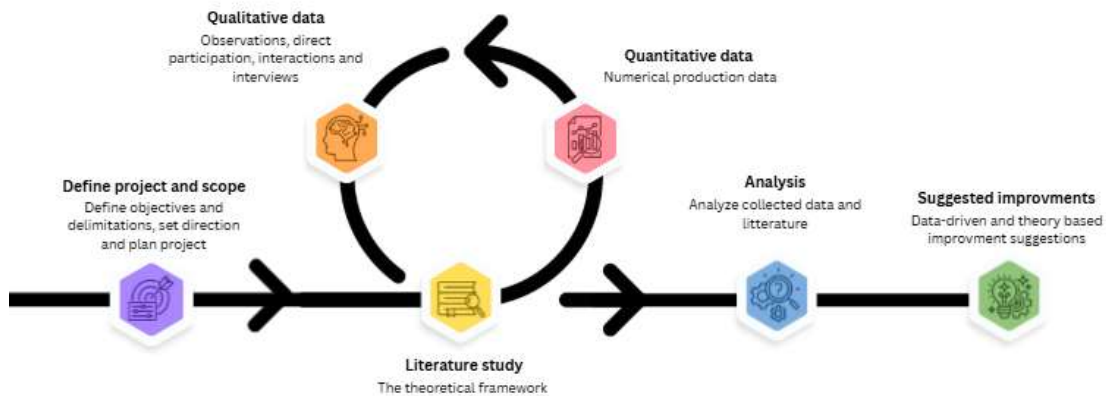


Figure 3. Visualization of the workflow and how the work process is structured.

3.2 Literature review

A literature review was conducted to form the basis of the theoretical framework for the study (Yin, 2018). As discussed earlier the literature used in this research project spans several areas within operations and production management, including lean management, productivity measurement, material handling, work design and assembly systems. However, the literature was not intended to provide a fully comprehensive overview of all production-related variables and theories. Instead, the selected theories and concept were chosen based on the relevance to the aim and research questions. The literature search was conducted using combinations of keywords related to the research area, such as “lean management”, “productivity”, “flow management”, “kanban”, “SMT”, “manual assembly”, “standardized work”. These keywords were used in combination with the Boolean operators “AND” and “OR”. Central concepts, terms, acronyms and synonyms were also used during this step to broaden the search. The searches were conducted in the Chalmers Library, Google Scholar and Scopus databases.

To ensure credibility and validity of the literature review, only peer reviewed articles were included and used in developing the research framework and analysis (Thiel, 2014). A quality assessment was carried out on the journals based on their ABS Journal Ranking, where the score 4-3 was considered very good, score 1-2 good and score 0 not prioritized. In addition to journals, the literature was complemented with refereed conference papers. A limited number of books were also involved, mainly to support the methodological part where journals and conference papers were limited.

3.3 Data collection

The project began with an initial gathering of basic qualitative data in the form of observations and unstructured interviews to better understand the situation at the company and determine the proper background, aim and methodology for the project.

After this, more advanced types of qualitative data were collected to get a deeper understanding of the current state at the company. Quantitative data was used as a tool to find and verify solutions within the scope determined by the qualitative data. The data was collected between roughly January and April 2026, with some data being recent and some being slightly older.

3.3.1 Qualitative data

The qualitative data collected in this research project was a combination of interviews, observations and direct participations. Data from many sources was combined to create a complete picture of the case, as there were variations in the data between the sources.

Interviews are an important source of a case study according to Voss et al. (2002). Physical interviews were conducted to collect qualitative data about the current state of production, challenges and experiences from key people. Key people consisted of production managers, team leaders, machine and assembly operators. The interviews in this case study consist of both unstructured and semi-structured interviews. The unstructured interviews were mainly exploratory conversations where the focus was on an overarching topic. These kinds of interviews were carried out throughout the whole research project and aimed to provide an understanding of the different subject areas, the context and to help the researchers orient themselves in the situation that the organization was in. These conversations also helped to guide the researchers for the later semi-structured interviews. During the unstructured interviews, the respondents were given a lot of room to control the conversation and its direction. Usually, only one or two questions were predetermined to be asked during the interview, while the remaining questions and direction of the interview were based on the respondent's answers. Notes were written down during the interviews and documented in Microsoft Word.

The semi-structured interviews followed an interview guide that served as a support with predefined topics and questions. The questions during the interview were mainly open-ended questions with the aim to go beyond short one-word answers and instead open for nuance. There was also room for follow-up questions to develop deepen reasoning. According to Bell et al. (2022), it is recommended to audio-record interviews to not only capture the answers but also how the respondents expressed themselves. The audio recording also helped in the process of transcribing the interviews, since there is the possibility of listening to the interview. The recordings were only made if the participants gave their consent and were used only for research purposes, such as listening back to the material to ensure correct interpretation. During the interview process, roles were clearly divided between the two authors to ensure a good structure. One of the authors was responsible for leading the interview, asking questions, and maintaining a conversation that was relevant to the aim of the interview. The other author took on an observing role where the responsibility was to document the entire interview. This division of roles enabled a structured procedure with a focus on both the conduct of the interview and the data collection.

The selection of the interviewees was based on selecting key people who had direct connections or responsibility for the subject areas of interest. Table 1 shows the interviews that were conducted, the duration and purpose of the interviews.

Table 1. Overview of the semi-structured interviews

Interviewee	Role	Duration (min)	Purpose of interviewee
A	Production manager	45	To understand the structure and assembly process of Alpha and identify improvement opportunities
B	Supply chain manager	60	To understand production distribution of Alpha, the assembly process, volumes and improvement opportunities
C	Production planner	45	To map the current production and planning for Alpha and SMT, including volumes and identify improvement areas
D	Production Technician SMT	45	To understand the SMT process and identify key causes of production stoppages, as well as opportunities to improve efficiency
E	Production Technician	40	To understand the current assembly setup for the Alpha and identify operational challenges and improvement opportunities

Observations is another source of evidence in case studies, allowing social and environmental conditions to be collected. These can be conducted in many ways ranging from formal, where structured tools are used to collect some special type of data, to casual, which could include taking part in meetings or simply watching employees do their work. Observations are an important complement to interviews, as they give a better understanding of the case through dimensions that interviews cannot convey (Yin, 2018). Observations, including direct participation, were conducted on-site in the production and aimed to observe production operations, including assembly work, material handling and operator movements. Direct participation accounts for when the authors participated themselves in assembly work.

Observation data could for example be in the form of photography and video, which can be particularly useful when studying humans (Bell et al., 2022). In this case, that could mean recording the operators as they perform their work. While time studies generate numerical values, the source material would in this case be aimed at a qualitative analysis, for example by looking at the method used by the worker. This could allow deviations from the method to be found, while also forming a basis for further method improvements (Almström, 2024).

3.3.2 Quantitative data

Before collecting the quantitative data, it is important to understand what data is available at the company. Then, any data related to the SMT production or final assembly could be gathered. An important quantitative data source is likely the ERP system, containing things like production volumes and production times, both planned and actual. With this data, it is possible to establish the current state of the operation. The SMT line itself could also be an important source of data, depending on what is

available. To be able to determine the OEE for example, there must be enough data for each of its three parts.

In addition to gathering this production data, time studies will be performed. This generates the theoretical time for an operator to perform a given task (Sellie, 2001), allowing for comparisons with the actual times in the operation. These time studies could be performed as video time studies, where the task is filmed and analysed afterwards. While time studies often are done with a stopwatch, a video time study would allow the worker to perform the full task without any interruption (Almström, 2024).

3.4 Data analysis

Qualitative data collection such as interviews, observations and informal discussions generates a large amount of unstructured material that needs to be systematically documented (Voss et al., 2002). Case-specific data were analysed using within-case analysis (Voss et al., 2002). A rich description of the case company's main operations was provided. This included detailed descriptions of the SMT process, the final assembly operation, material flow and assembly work methods related to the research questions. The findings were then analysed and compared with the literature.

The quantitative analysis will follow a descriptive analysis approach (Bell et al., 2022). This, because the purpose is to interpret the production data and calculate production metrics to gain an understanding of what the operating performance looks like, rather than testing different hypotheses. A descriptive analysis is appropriate to use when measures such as totals and averages are used. Since the results of the quantitative data are not to be generalized statistically, but the study aims to interpret a specific case, the study follows this approach. The performance of the pick-and-place machine will be evaluated using calculations on the available data, attempting to determine various KPIs. The time distribution of the machine will be calculated and analysed to find the important barriers for improving the efficiency. For the final assembly, time-based analyses will be carried out on data provided by the MTM-SAM analysis and the ERP system. Microsoft Excel will be used as the main tool for handling, calculating and visualizing numerical data. The quantitative analysis will contribute to an understanding of the average situation, rather than being limited to the observations.

3.4.1 Root cause analysis

When solving problems and doing improvements work, it is important to understand why a problem occur according to Gangidi (2019). A root cause analysis can be used to avoid superficial solutions that only address the symptoms and not the actual underlying root cause. The “5 Whys” is an iterative method that aims to identify the root causes by looking beyond symptoms and identifying the underlying causes by repeating the question “why?” multiple times. This form of analysis approach will be used when analysing improvement suggestions related to research question three or when understanding the current state of the assembly process related to research question two.

3.5 Ethical considerations

The ethical aspects are important to consider when conducting business research according to Bell et al. (2022). Four different risk areas are highlighted, such as harm of participants, invasion of privacy, informed consent and deception.

Harm to participants involves not only physical harm, but also the impact on the participants' self-esteem, stress or anxiety. The study will not expose the participants to any physical risk. However, there is a risk that participants will feel monitored or judged. To minimize this, there will be clear communication that participation will not affect any form of employment or personal performance assessment, but that the study focuses on processes. In addition, the results will be presented at a group or system level to reduce the risk of uncomfortable participation.

Releasing sensitive data can harm both individuals and the company (Bell et al, 2022). All sensitive or confidential information will be handled with care, only used for research purposes and processed in accordance with the company's wishes. The researchers will be careful to discuss sensitive information in an open environment. Anonymity will be maintained where pseudonyms are used and person-identifying references will be avoided to ensure anonymity. Photography and video recording may involve personal or sensitive information. In these cases, informed consent will be obtained before it takes place. This form of material will only be used for internal use to allow the researchers to review observations, which afterwards will be completely removed.

All participants in observations or interviews were informed about the study and its aim. Interviewees were also allowed to ask questions for clarification and were asked for informed consent (Voss et al., 2002). During interviews or any surveys, participants received information and interview questions prior to the interview, both to decide whether they want to participate but also to prepare themselves (Bell et al., 2023).

The research project followed the ethical guidelines that are highlighted in this subsection. Clear information and transparent communication were ensured throughout the process to minimize misrepresentation or other ethical risks.

4 Results

The result is divided into three subsections, one for each research question. Thereby, the first subsection covers the SMT production, while the second and third subsections cover the final assembly.

4.1 SMT line production

Surface mount technology (SMT) is a widely used manufacturing method for mounting electronic components, such as resistors, capacitors, light-emitting diodes (LED) and other components directly onto the surface of printed circuit boards (PCB). By observations and interviews, it was shown that the process consists of a loader, panel scanner, solder paste printer, pick and place machine, quality control, reflow oven and finally unloading, see Figure 4 for an illustration of this. The loader is located at the beginning of the SMT line and feeds panels of PCBs one by one onto a conveyor belt. This is followed by solder paste printing, which aims to apply solder paste, a paste made of metal alloys, in the right place and in the right amount for each print. Component placement, also called pick-and-place, is performed by automated high-speed pick-and-place machines that pick components and place them in the paste at the already defined locations. This motion is usually done by an X-Y gantry system or a robotic arm equipped with vacuum nozzles. This is followed by the quality control, which is only carried out on the first board in each order. Then the soldering takes place in a reflow oven which consists of a conveyor belt. Finally, the panels are placed in cassettes of 50 pieces.

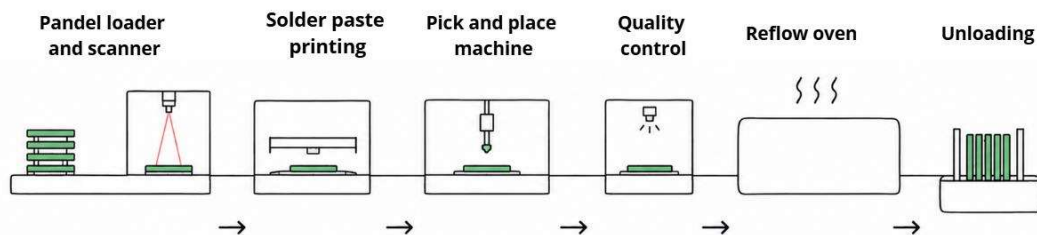


Figure 4. Illustration of the SMT line.

The company in this case study has a single SMT line which is staffed by a single employee during the day and sometimes also by a single employee during the night based on demand. According to employees at the company, the pick and place machine is the most important part of the line. This machine is divided into two parts, where the first part adds small components and the second part adds slightly larger ones. One of the operators stated that picking and placing these larger components takes more time than it does for the smaller ones. As for the planning of the production, the operators receive what production orders are needed but are free to make the detailed schedule themselves. The planned times for production orders are supposedly based on historical data, but they rarely match the actual times in the production. In fact, orders can sometimes be completed much faster than planned.

Setup times are described as one of the main sources of production losses by the operators. According to one of them, when producing large orders, the line works

efficiently, but when producing smaller orders, there could be a lot of time spent on setups. The time it takes to prepare the machine depends on differences between products, such as board width, components and frame replacement and cleaning in the solder paste application. Orders that have similar circuit boards but consist of different components could be run in sequence to reduce setup time. Scheduling is also a factor that affects how much the line can run as it was described as frequently changing. According to interviews, orders can be added or changed at short notice. This can result in an order being prepared by the warehouse and operators but then moved to another day in the run planning. Material availability is also mentioned during interviews as a source of loss. Components and circuit boards can arrive late or be unavailable. This can result in production being halted or time being spent finding the right materials. Orders can also be split due to material shortages, with part of the order being produced and the remaining quantity being completed on another day, increasing the number of setups. With the correct sequencing of orders the issue could be mitigated, something that had been heavily requested by the operators. However, while the production staff wants the planning to minimize setups, the managers want the planning to match the customer orders as closely as possible. With no concrete data available on the losses in the production, little action appears to have been taken to improve the situation.

4.1.1 Operational data collection and analysis

Observing the SMT line and interviewing an experienced employee revealed that the theoretical cycle times for the pick and place machine are available in the software used for programming it. The theoretical time is the time between products exiting the machine in the theoretical case that there are no disturbances. Simultaneously, it was revealed that a production management software at the company collects and presents data over various events from the pick and place machine, showing what happened at which time. By filtering out the events where the machine outputs a product, the actual cycle times can be found. Then, any cycles that include longer stops or micro stops (shorter than a few minutes) can be identified. The cycle times can be visualised with a control chart, showing how they change over time and perhaps allowing patterns to be found. In this chart, there could also be a comparison with the theoretical cycle times.

Having theoretical and actual cycle times for the pick and place machine, OEE can be used to measure the efficiency of it. First, there are some definitions needed to create the availability and performance KPIs. The cycle time threshold between longer stops and micro stops will determine if a stop is classed as a performance or availability loss. One manager stated that this threshold could be 5 minutes, which subsequently was used in the analysis. Then, the total production time including micro stops becomes the sum of all cycles below 5 minutes. This is compared with the total theoretical time for an order of the same size to calculate the performance. Next, the operators have flexible hours, meaning that there is no true daily planned time. One solution could be to simply take the total time spent on an order and subtract any planned breaks during the time of the order. Doing this will likely highlight any longer stops outside of these breaks as availability losses. By subtracting the planned stops from the total time, it is also possible to estimate the planned time, which is then used in the calculation of availability.

First, three production orders of 148-MCB-372 were analysed to generate the results presented in Table 2. Each panel processed in the SMT has 6 PCBs, with each PCB receiving 35 components. In addition to calculating the theoretical and average cycle times, the mode cycle time is used to see if there is a speed loss or if the machine is getting bottlenecked.

Table 2. Average cycle times and KPIs across three orders

Theoretical cycle time	23.6 seconds
Average cycle time	38 seconds
Mode cycle time	34 seconds
Average availability	80.4%
Average performance	63.1%

For one of the orders, Figure 5 visualizes the cycle times below 5 minutes, with the number of cycles on the x-axis and the length of each on the y-axis. This figure shows how the cycle time sometimes are around the theoretical value 23.6 seconds but usually are around 34 seconds. It also shows patterns of recurring micro stops that increase the cycle time to around 55 seconds, as well as other types of shorter stops that appear to have no pattern. In the figure, there are special situations where the cycle time is lower than it theoretically should be. According to one of the operators, this could happen if there is a disturbance at the end of the machine or down the line, in which case units will build up inside and before the machine, allowing them to exit quickly once the disturbance is handled. This could become problematic, especially if it occurs too often.

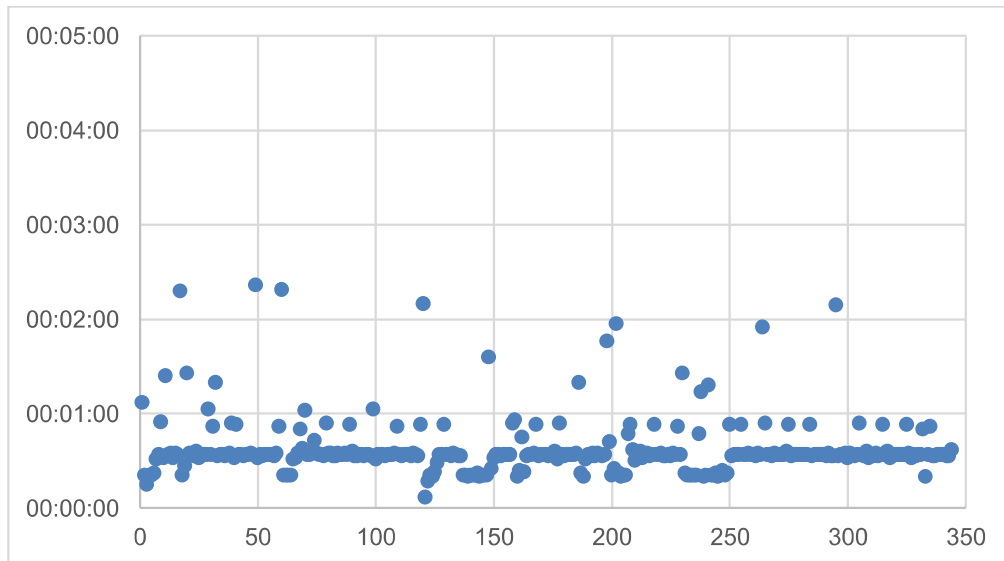


Figure 5. Cycle times below 5 minutes when producing 148-MCB-372

The same data can also be visualized with a histogram, showing the frequency of different cycle times. In Figure 6, 30-35 seconds has the highest frequency while 20-25 seconds has the second highest frequency.

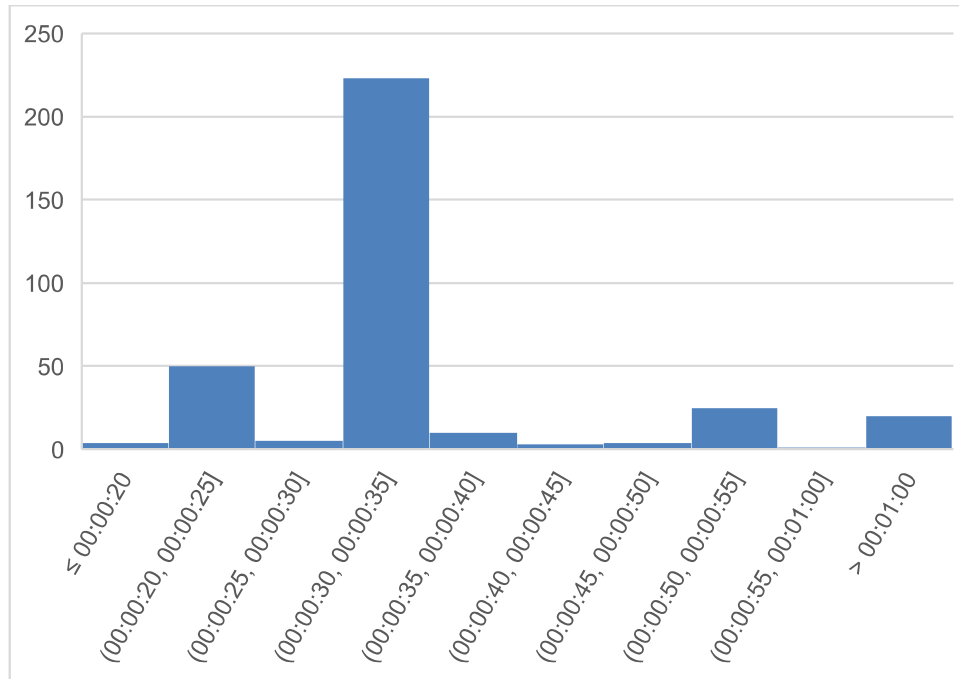


Figure 6. Histogram of the data in figure 5

Next, the product 004-MCB-668 was studied. In this case, each panel has 10 PCBs, each of which have 50 components. Four orders of this product were analysed with results presented in Table 3, and figure 7 showing cycle times below 5 minutes for one of the orders. For that specific order, the number of cycles deviating from the theoretical time is quite small. This is also reflected in the performance, being much higher here than for the product previously analysed.

Table 3. Average cycle times and KPIs across four orders.

Theoretical cycle time	45.6 seconds
Average cycle time	59 seconds
Mode cycle time	45 seconds
Average availability	70.3%
Average performance	80.0%

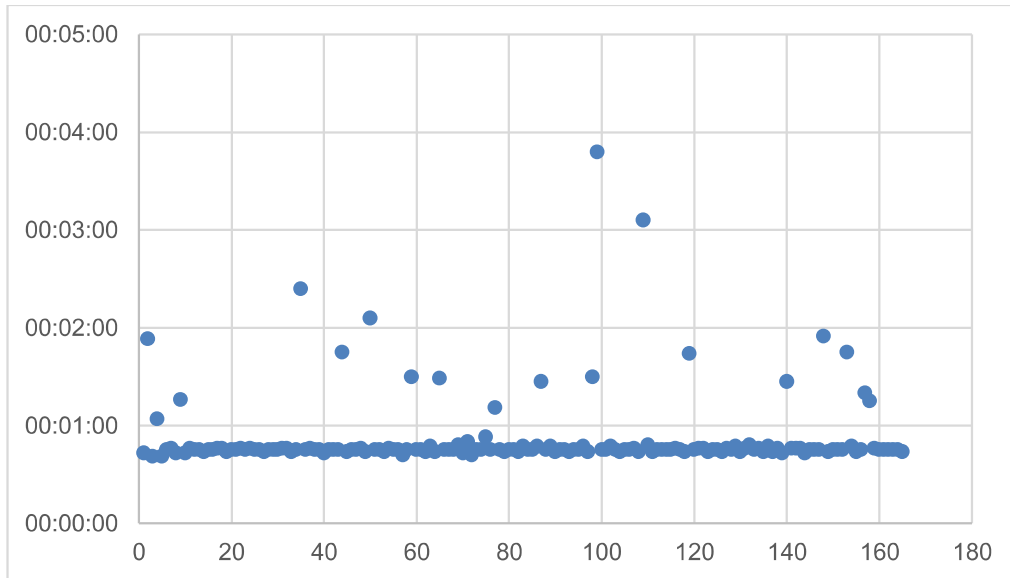


Figure 7. Cycle times below 5 minutes when producing 004-MCB-668.

Meanwhile, the histogram for this data in Figure 8 shows that the cycle times are centred around the theoretical time, with very few cycles significantly surpassing it.

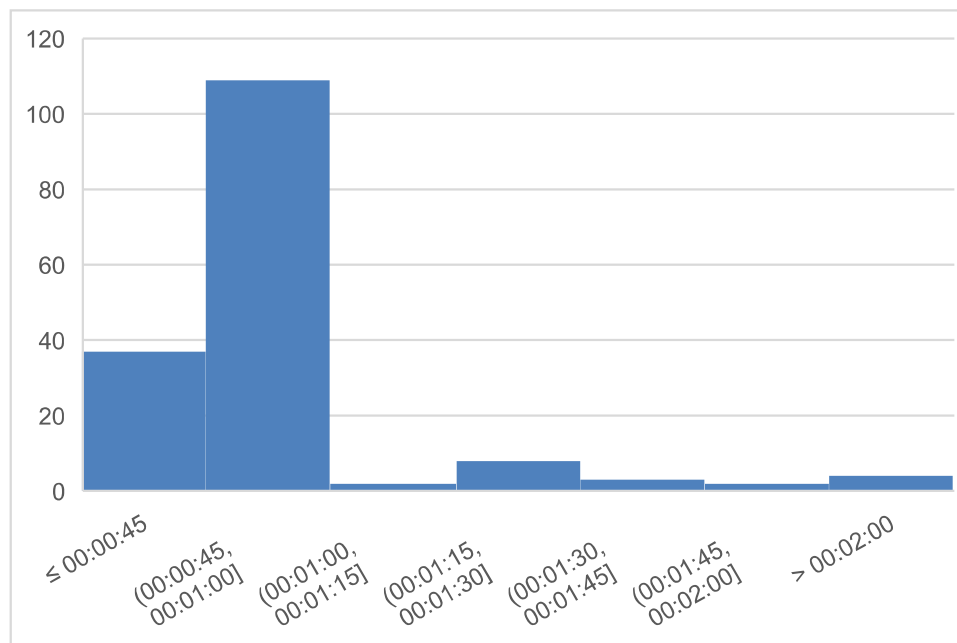


Figure 8. Histogram of the data in figure 7

The quality in the SMT production is perceived by the company to be so high that it is not valuable to measure. In some cases, very few products are tested compared to the order sizes, and the results are generally not logged. If an obvious defect is found in the line, that specific panel could be removed, and another one could be added. The only quality metric that seems to be of importance at the company is the number of customer complaints, which according to one of the managers also is very low. Customers with recurring orders could in some cases simply get additional products in their next order if any in their current are faulty, without the company considering any intervention in the production to be necessary. This attitude towards quality at the

company makes it impossible to derive a meaningful quality KPI, which in turn makes it impossible to calculate a true OEE.

4.1.2 Analysis of full working days

Calculations on individual orders may not give a complete picture of the state of the production system. Depending on which time of day the orders take place, there could be different kinds of losses. To finalize the data collection and analysis of the SMT line, entire working days must be analysed. The first day analysed only sees one product being made, while the second day sees 7 products being made.

The first full day to be analysed is 2026-01-09. This day already appeared in 4.1.1, and only that specific product was manufactured during this day. With all required data already gathered, this is a given option for analysing a whole working day. The data is presented in Table 4 and Figure 9. This day has many micro stops of a slightly longer length with no apparent pattern, causing the performance to be lower than what was presented in 4.1.1.

Table 4. Cycle times and KPIs for this working day

Theoretical cycle time	45.6 seconds
Average cycle time	69 seconds
Mode cycle time	45 seconds
Availability	83.7%
Performance	68.6%

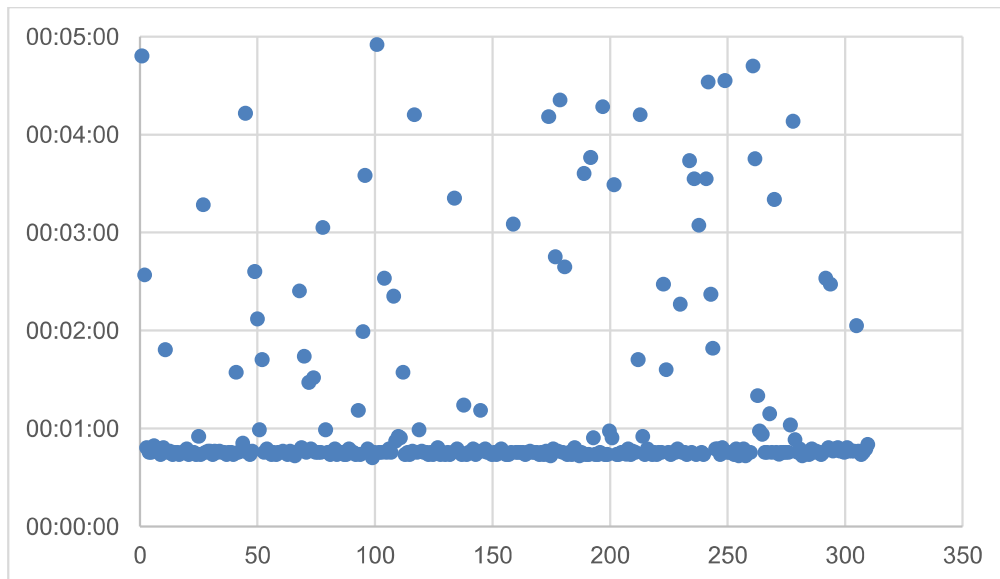


Figure 9. Cycle times below 5 minutes this day

This increase in micro stops is also shown in Figure 10, as there now are more cycles on the higher end of the histogram.

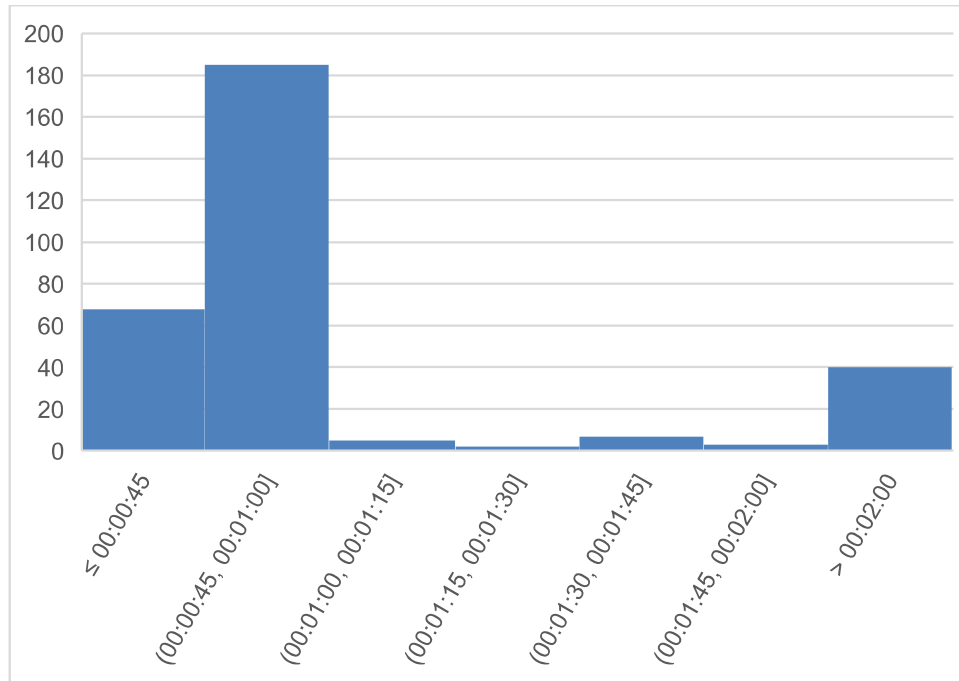


Figure 10. Histogram of the data in figure 9

With the same data, it is also possible to estimate how much of the machine time is distributed on production, setups, planned stops and unplanned stops. By looking at the raw data, stops that are in the very beginning or end of an order could be labelled as potential setups. Then, any known planned stops, including breaks as well as up to 15 minutes of preparation and cleaning in the beginning and end of shifts, could be labelled as such. If the preparation and cleaning is longer than 15 minutes, the amount of time exceeding 15 minutes must be labelled as an unplanned stop, given that the operators only are allowed to spend 15 minutes on this task. Finally, all other stops could be labelled as unplanned stops. This entire process of labelling cycle times as production and micro stops, setups, planned stops or unplanned stops is shown in Figure 11.

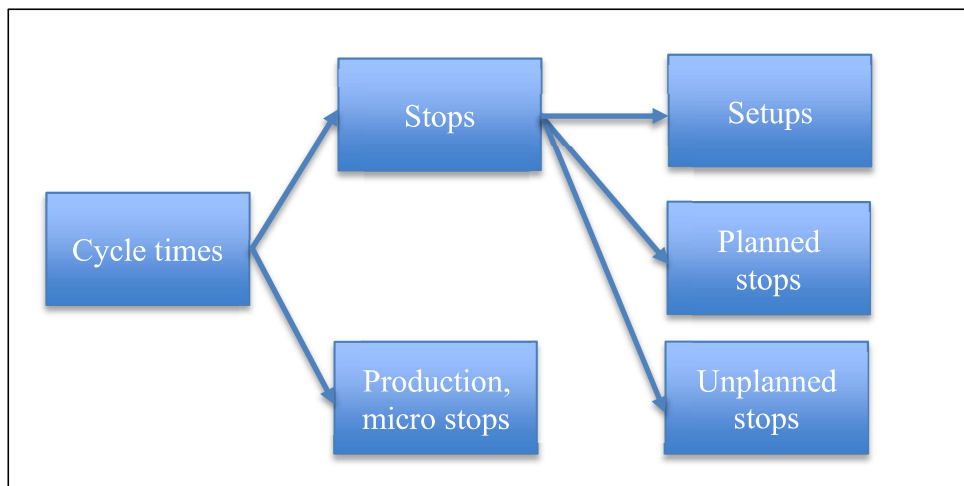


Figure 11. The process of labelling cycle times developed in this research project

Performing this process on the data from this day resulted in the findings presented in Figure 12. The figure shows approximate production, setups, planned stops, and unplanned stops. These are estimated values; however, the overall proportions of time should still reflect the real situation to some degree. Note that the proportion spent on production in the graph is not the same as the availability, as availability compares the production time to the planned time while this compares the production time to the total time with an operator present in the operation.

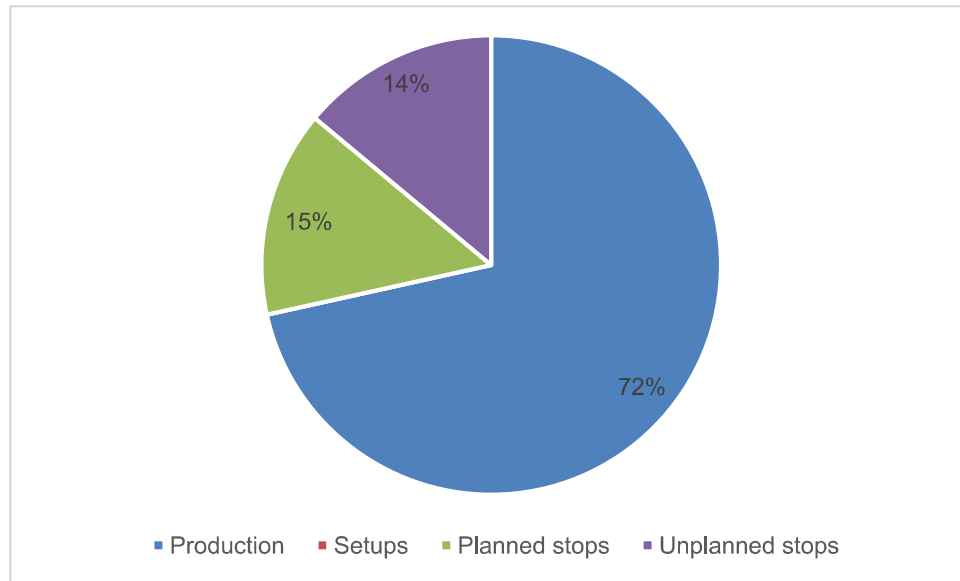


Figure 12. Estimated time distribution for the SMT line this day

As this analysis is based on a manual assessment, the numbers will not be precise. While these are estimated values, the overall proportions of time should still reflect the real situation to some degree. Note that the proportion spent on production in the machine time distribution is not the same as the availability, as availability compares the production time to the planned time while this compares the production time to the total time.

While only one product was made during the previously analysed day, a day where multiple products are made must also be analysed to verify the operators' statements that setup times are important losses. The day selected for this was 2026-03-10, which according to an operator was problematic due to having many small production orders. This analysis requires a bit more work, as each product has its own theoretical cycle time. To calculate the total theoretical time, cycle times are multiplied with order sizes in Table 5.

Table 5. Theoretical times for products manufactured this day

Product	Cycle time	Number of units	Total time
148-MCB-232	00:46.7	100	01:17:50
148-MCB-006	00:42.9	32	00:22:51
148-MCB-020	00:40.3	14	00:09:24
156-MCB-073	00:26.3	33	00:14:28
109-MCB-1109	00:39.1	10	00:06:31
177-MCB-385	00:28.6	7	00:03:20
148-MCB-391	00:35.0	16	00:09:20

By summing the total theoretical times for the products, the theoretical time for the entire day can be calculated to 02:23:45. These theoretical times then result in the KPIs presented in Table 6.

Table 6. Cycle times and KPIs for this working day

Average theoretical cycle time	40.7 seconds
Average actual cycle time	55 seconds
Availability	52.9%
Performance	78.2%

As there are different theoretical times, they are added to the cycle time graph in figure X for easy comparison with the actual times. Just like in 4.1.1, products with a theoretical time below a certain level might be bottlenecked by another part of the line. For some of the later products, there are quite a lot of instances where the cycle time is lower than the theoretical time. As also mentioned in 4.1.1, this could occur in conjunction with disturbances. However, the number of times it happens in Figure 13 appears to be too large, given that it only should occur in special situations.

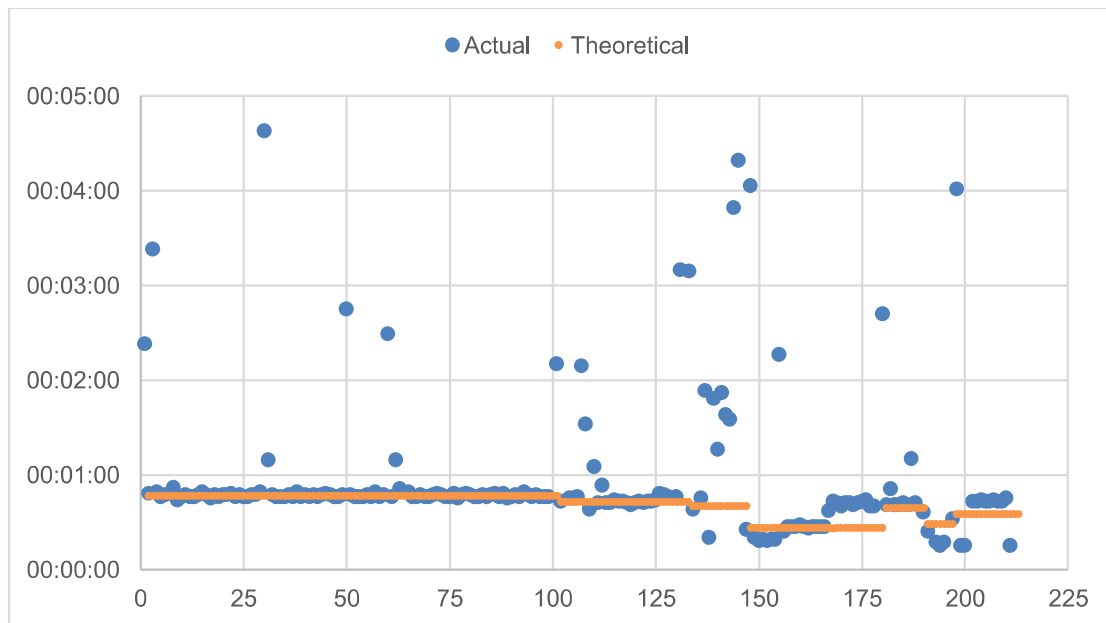


Figure 13. Cycle times below 5 minutes this day

Meanwhile, figure 14 shows the distribution of the cycle times. Unfortunately, it does not allow the theoretical and actual cycle times for each product to be compared as in figure 11, instead simply showing all cycle times at once.

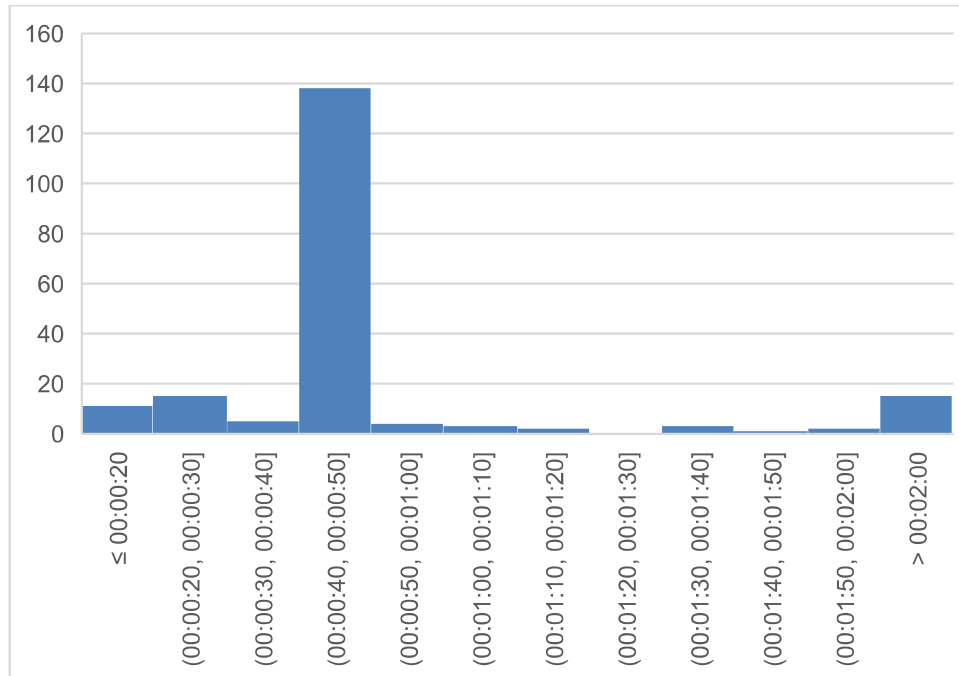


Figure 14. Histogram of the data in figure 13

While having many setups clearly seems to reduce the availability, viewing the machine time distribution in figure 15 makes it even more clear. This analysis shows that a significant portion of the total time could be spent on setups if too many few products are made in the same day. As for the preparation and cleaning of the line, it is unknown how much of it should be labelled as a planned stop and how much should be a setup in the case that a new product is made in the morning compared to the end of the previous working day. Once again, up to 15 minutes added to the planned stops, but any amount exceeding that is added to the setups.

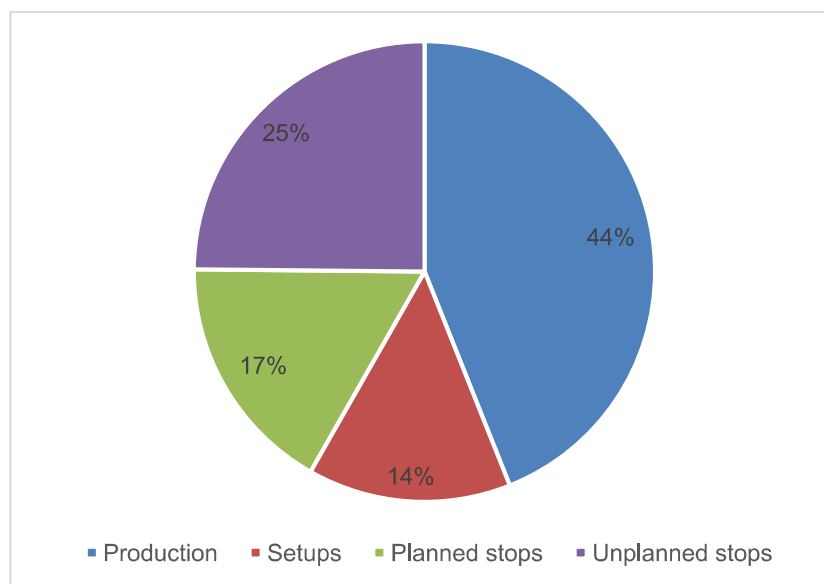


Figure 15. Estimated time distribution for the SMT line this day

Finally, the two days are compared in table 7 over number of products as well as their KPIs. Then, their resource statistics are visualized in figure 14. This analysis indicates

that an increasing number of products made in a single day results in a decreasing availability. Performance on the other hand appears to be more tied to the type of product rather than how many are produced, given that it is almost 10 percentage points higher for the day with multiple products.

Table 7. Comparison of KPIs

Date	2026-01-09	2026-03-10
Number of products	1	7
Availability	83.7%	52.9%
Performance	68.6%	78.2%

If quality is selected to be 100% for the calculation, the OEE would be 55.8% and 40.7% in these two cases respectively. The real OEE, with quality losses considered, will be even lower.

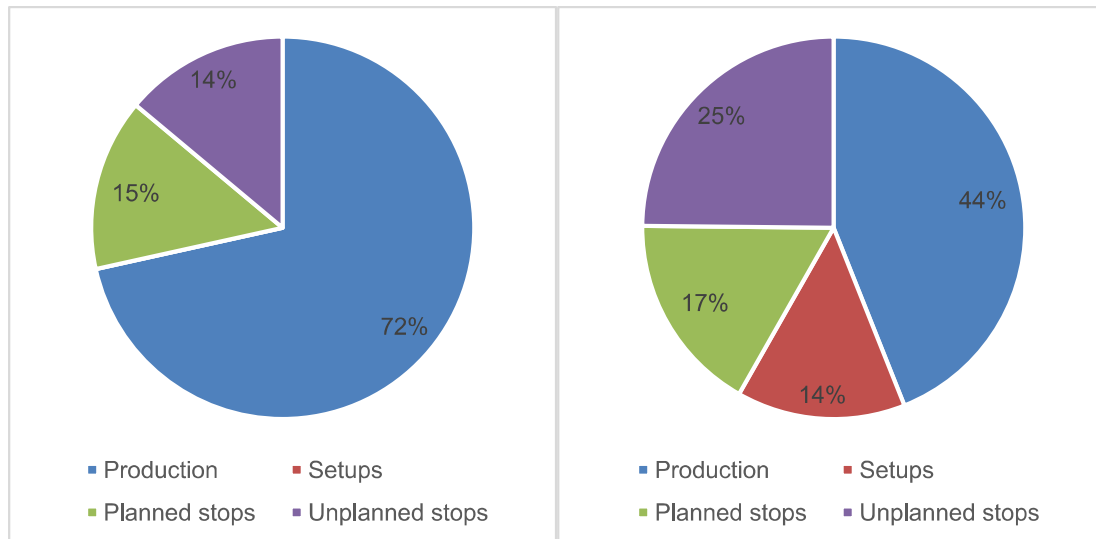


Figure 16. Comparison of time distributions when making 1 product or 7 products

Comparing the estimated time distributions from the two working days in figure 16 shows the significance of setups, confirming the statements from the line operators. There is also a significant difference in unplanned stops, but it is unknown to what extent this is affected by the planning. It is important to note that the analysis is very approximate, as only someone constantly observing the line can label the stops correctly. Preferably, this should be the operators themselves.

4.2 Current state of the final manual assembly

The product family chosen for analysis in this thesis, Alpha, is a circular lighting product that comes in three sizes, has recently been introduced and is expected to continue selling for several years. This product is the first in a new generation of luminaires, and according to interviews, any improvements made to the manufacturing of this product are expected to be of good use for the products that are introduced in the future. Customer demand for Alpha is characterized by high variability, as it is mainly project-based. Interviews indicate that order sizes can vary significantly, from small to large quantities. The customer lead time is approximately two weeks, with an additional safety time of two days.

Alpha products consist of two main parts, the body and the driver box. An illustration of exploded view with components can be seen in Figure 17. The body includes a front housing with an integrated optical cover. In addition, the body contains a PCBA (LED PCB), which generates the light. The PCBA is secured to the housing by a collar, which connects and holds the components together. The driver box consists of a rear housing, which is mounted to the wall or ceiling, and contains the LED driver. For each size of Alpha, there are two different driver configurations, with a third being planned for the largest size. The six current configurations are created with four different drivers whose settings are changed during assembly to match the requirement. The collar is a part of the body and connects the components together, as well as determines whether the luminaire provides indirect light or not. Depending on whether a transparent or white collar is used, the luminaire will either provide upward light or not. There are several variants of both the body and the driver box, and different product configurations are created by combining these components in different ways.

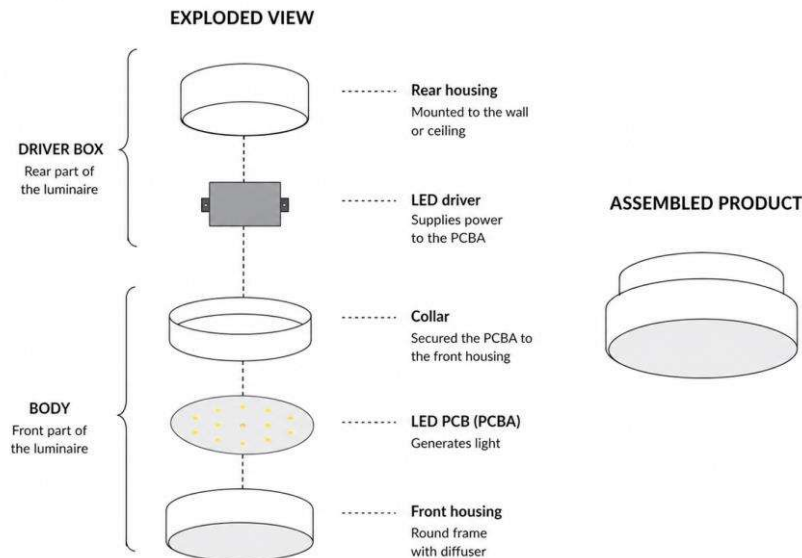


Figure 17. An illustration of the assembled product and exploded view of the components.

4.2.1 Production approach

The product is prefabricated in China before being sent to Sweden. However, the products can enter the final assembly process in different states and thus contribute to multiple assembly approaches in Sweden, see Figure 18 for an illustration of the two production approaches. One approach is based on China delivering pre-assembled products based on a forecasted demand. If this forecast were not to match the actual demand, two existing products would be dismantled with body and driver box to create two new products, one fulfilling the customer order and shipped to the customer and the other being stored in the warehouse. The other approach is to deliver semi-finished modules, i.e. a lamp with body and empty driver box. In these cases, a driver is fitted into the module during final assembly in Sweden according to customer requirements. In addition, the collar can also be removed and replaced to achieve the desired lighting configuration. Interviews showed that the standard module delivered from China consists of the transparent collar and that products that

are not to have indirect light always need to undergo a change where the transparent collars are replaced with white collars. As a result of these two approaches, the final assembly process involves recurring rework operations, where components are added or parts are replaced and recombined to meet demand.

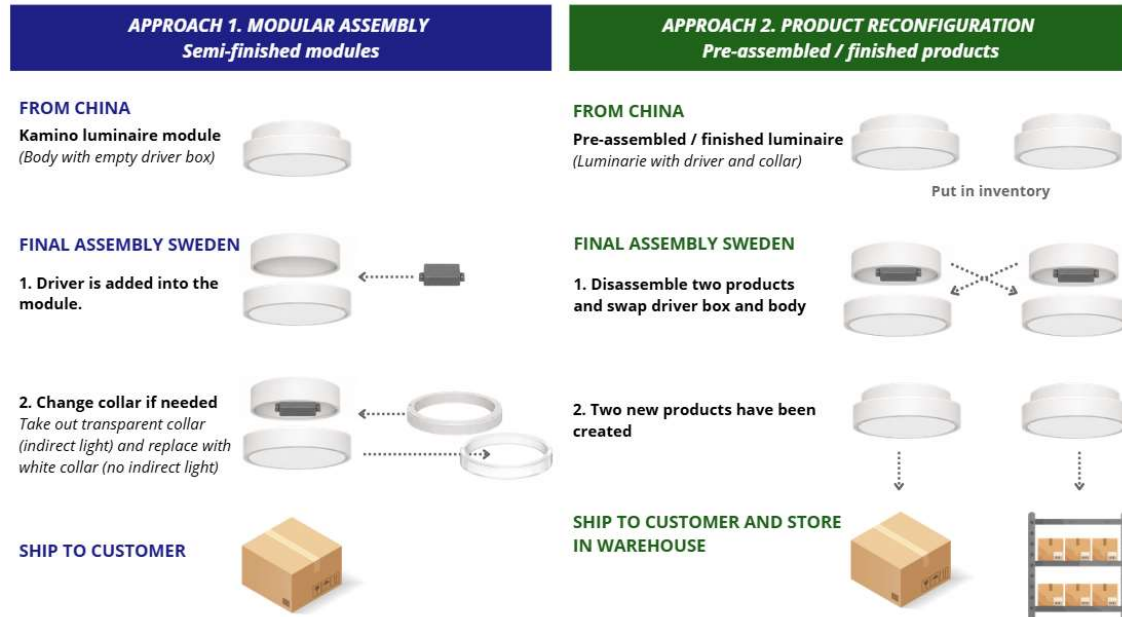


Figure 18. The two production approaches for the Alpha products.

4.2.2 Material flow and layout

The current production layout and observed movement patterns for four processes related to the assembly of Alpha products are presented in Figure 19. The space consists of a warehouse, the grey area, a production area, inside the dotted lines, and in between an open space with an unloading area which is marked in green. The dotted lines in the figure represent plastic strip curtains suspended from the ceiling, which can be passed through by operators and do not form rigid barriers. The production area consists of seven tables which are intended for the assembly of all their products, where two of them are intended for Alpha. These two tables are adjacent to a pillar, seen as the black square in the figure, which restricts the available space. Because of this, materials were placed further away from the workbench, sometimes behind the worker.

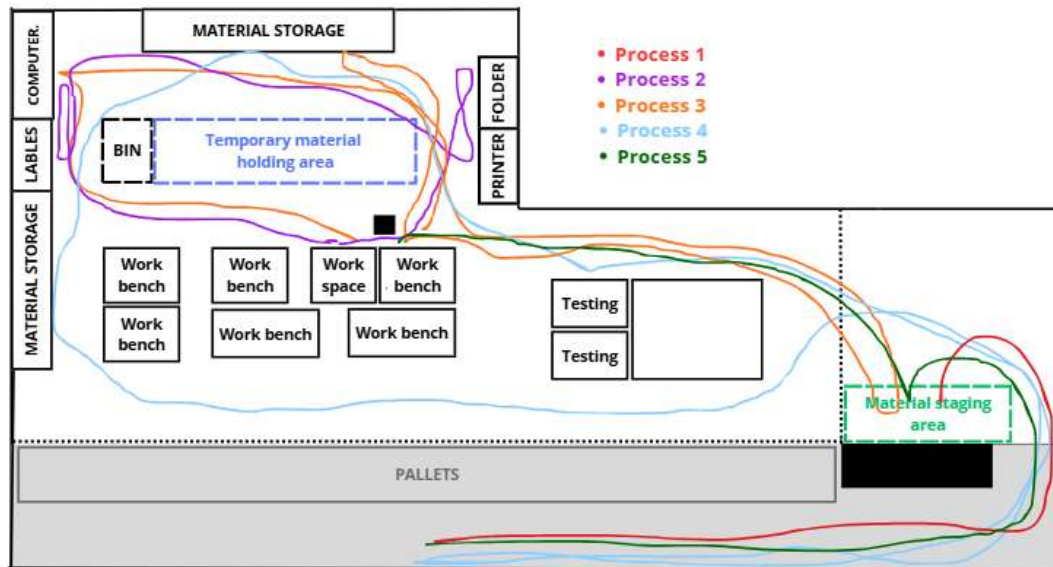


Figure 19. Layout of the production area and spaghetti diagram of assembly-related processes.

The observations indicate that the current material flow within the final assembly is characterized by unnecessary transportation, inconsistent material handling routines and a lack of standardized flow structure. All materials required for an order, including screws, metal clips, drivers, collars and Alpha products or modules, are picked by the warehouse and delivered to the green material staging area on pallets or trolleys. This process is illustrated by process 1, red path, in Figure 19. According to interviews with operators, material should be placed here for a maximum of one day, but material is collected here for considerably longer than that, which resulted in a large area with a lot of material. The blue marked area, temporary material holding area, is used for temporary storage of materials related to orders that are being processed.

Materials are placed in certain sections of the area, support equipment like label and paper printers in others, and finally, benches for assembly and testing are grouped in a large part in the middle of the area. In one corner of the space there is a computer and a label printer, and on the opposite side there is a printer and a folding machine for product manuals. Process 2, purple, traces the path for printing labels and manuals, where these are placed in different places. Along two of the walls there are shelves with boxes consisting of materials such as screws, drivers and other components for products. One of the storage racks with drivers is connected to their ERP system that generates notifications when new orders need to be placed, based on stock level and safety stock. In addition, another storage rack system was used for smaller components. There, empty boxes were refilled manually by the operators at the end of each shift, see Figure 20. Interviews showed that all racks were used for other products, but not for Alpha even though space was available. In addition, it was revealed that some material on these racks was also out of date and no longer relevant. Process 3 in Figure 19, orange, illustrates when the operator picks up the order material at the material staging area outside of the assembly area and empty boxes at the material storage and brings this to the workstation. Process 4, blue, shows

the path for material replenishment from the warehouse to the material storage areas within the assembly area.



Figure 20. Image of storage area with boxes used to organize materials for product assembly.

All materials are delivered to the respective orders and follow the same flow through the plant. The material is not packed in the exact quantity needed for the respective orders, but the material comes in large bags or boxes. Through observations and interviews, it was shown that excess material was put back on the pallet or cart to be returned to the warehouse after the order was completed. See Process 5, green, in Figure 19.

4.2.3 Setup-activities and workstation

Before the assembly of Alpha products could begin, the operator needed to perform a few preparatory tasks. Several product labels needed to be printed. Based on the author's observations, the operator selected the right labels and the quantity in the computer that got printed out by the label printers in a long strip that was collected on the floor. This was collected and rolled up by hand by the operator. This entire process could take several minutes. Installation manuals were also printed out from the computer, printed by the printer and placed in the folding machine that folded them in half. This process also required a few minutes of time. The equipment for these tasks was in different areas in the assembly area. During observations, it was shown that other preparatory tasks were carried out during this time, and sometimes not.

Then the workstation needed to be set up and organized. This was done by the operator by placing the material near the workbench that would be used for assembly. If the material was placed inside the production area, it was moved closer to the workbench, but if it was placed outside the production area in the green unloading area, the operator would need to go there and move the material inside first. Smaller components were usually placed on the workbench in their original packaging or in

containers that the operators picked from shelves placed along the wall. Larger components, such as Alpha modules or products that needed to be reassembled, were stored on low carts behind the operator, while fully assembled products were placed on carts diagonally behind. Positioning the larger components like this required the operator to turn, walk, and bend during each assembly cycle. This setup introduces additional movement into the process, as materials are not consistently placed within the operator's immediate reach.

The tools were stored in clear and marked positions above the work area before and after assembly. But it was observed that there is no dedicated or standardized location for tools used during assembly. The tools and materials were taken down by the operators at the beginning of the process to keep them within reasonable reach during assembly. The tools were thereby placed in various locations on the workbench among materials and components. This resulted in operators sometimes having to search for tools, lift materials or reach to find the right tool.

Interviews revealed that operators have 15 minutes at the beginning and 15 minutes at the end of each shift to prepare and reset workstations. This includes removing materials from workbenches to the blue temporary material holding area, but also replenishing materials in the empty storage boxes in the material storage along the wall. Materials and work areas are cleaned away at the end of each shift, even for ongoing orders, in case, for example, an operator is sick and does not show up the next day.

4.2.4 The assembly process

The two most common operations during the time of the study were the installation of a driver to an Alpha module and the replacement of a collar.

Each process begins with a packaged Alpha module or product being removed from the load carrier behind the operator as previously mentioned. According to observations, existing labels are removed from the packaging, as these correspond to the current variant that will be configured for a different product. The box is opened; the product is lifted and turned over. The paper wrapped around the product is opened by tearing off tape. Observations have shown that the tape repeatedly tore the paper. According to interviews with operators in production, it is difficult not to tear the paper at this stage. With the product now accessible to the operator, the driver box is separated from the body with a twist, and the appropriate work is performed.

With the installation of a driver in the driver box, the process begins with a label being placed inside the driver box and one inside the body. Cutters are used to remove several numbers of plastic pieces from the driver box, creating a mounting position for the specific type of driver. A plastic piece located beneath the wall power connection, between the driver and the external power supply, was cut away, after which a label indicating the terminal markings was applied. The driver is put in place and configured with a screwdriver by adjusting small switches on the driver. To fasten the driver, a metal clip and two screws are picked up. The metal clip is placed on top and screwed in place with an electric screwdriver. The cables are connected to both sides of the driver, and observations showed that it was sometimes unclear how

these should be connected, which took extra time. The test process was such that the driver box and body were connected while the driver box was connected to the test equipment. After a few seconds, the test was completed, allowing the body and driver box to be disconnected again. The connections on the driver were covered with plastic covers that were screwed into place. Finally, the driver box was assembled with the body, wrapped up with the paper and turned the right way around. Manuals were placed on the product before the box was closed again. Two new labels were placed on the box, and the operator placed the finished product on a cart behind.

The process of changing the collar takes longer time. Once the driver box and body were separated, labels were inserted into the body and the driver box. Next step was to unscrew the collar from the body, which consisted of several screws and took quite some time. The screws were placed on the table. The collar is turned over and to release the PCBA from the collar, several more screws are unscrewed which were also placed on the table. The PCBA is transferred to the new collar and screwed in place and then finally screwed onto the body. The previously used screws are used for this. However, during observations, it was noticed that screws could be lost among the material, fall to the floor or get mixed up, which wasted time. The screws are quite small and handled manually, placed on the screw bit by hand even though it is magnetic. When working on the PCBA and collar, the LEDs are exposed, with some being very close to the screws. The old collars are placed on the side of one bench, stacked in a pile. The test process went like the previously mentioned process, and the final product was wrapped up with the paper, turned around and placed in the box. Installation manuals for the customer are added on top of the product and the box is closed. Finally, two new labels are added to the box, and it can be placed in the load bearer for finished products behind.

Figure 21 is an illustration from an observation of how the material was placed around the workstation and how the operator needed to move, bend and turn to access the right material. The grey area symbolizes the workbench where the assembly took place. The white squares symbolize boxes or trolleys with material. The red marking illustrates how the operator moved during an assembly cycle that started at the red dot at the workbench.

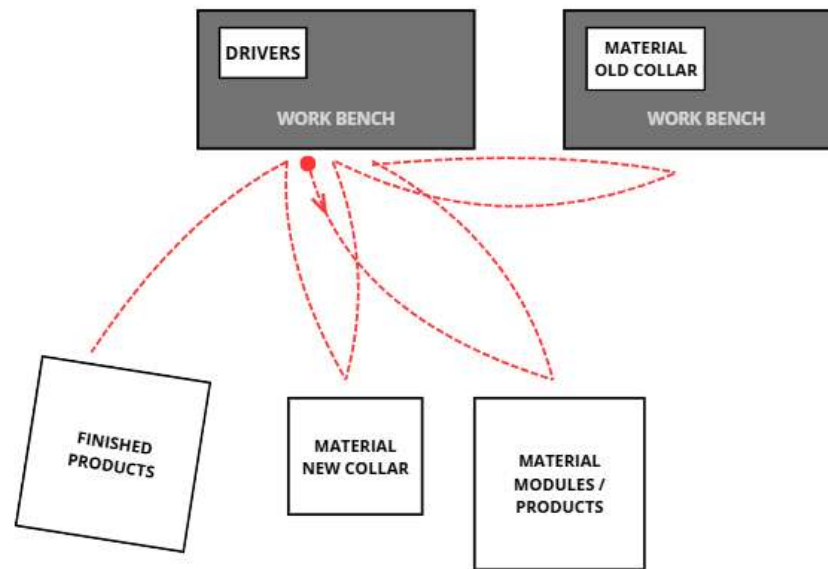


Figure 21. Illustration for material planning and operator movement during an assembly cycle.

4.2.5 Work method variations

Observations and direct participation in the assembly process of Alpha revealed a clear variation in working methods between operators. In addition, several challenges that inexperienced operators may encounter when assembling this product were revealed. The participation also revealed that many motions in the assembly require precision, which was not detected from an outside perspective. This is an important detail for carrying out the SAM analysis correctly.

During interviews with several managers at the company, it was found that work instructions were generally considered inadequate in assembly work because experienced operators rarely used them. Instead, there was an expectation for operators to learn tasks through practical experience but also to take support from colleagues and ask for help. Observations and direct participation, however, revealed that less experienced operators sometimes needed help during assembly and asked colleagues for guidance on assembly steps or product configurations.

There are numerous critical steps in the assembly process that must be done in the right way and order, requiring the inexperienced worker to have instructions at hand during assembly. At one of the workstations there was a computer screen where instructions could be easily accessed during the process. At the remaining workstations it was instead required to have the instructions in paper format. However, instructions for certain assembly processes were not available to assemblers at the beginning of the project due to miscommunication between different parts of the company. This forced employees to ask others for help. During direct participation, those instructions that were available were found to be adapted for more experienced operators, as some steps were missing or sometimes unclear, decreasing the assembly speed. Furthermore, all information, instructions and documents for products were accessed digitally via a shared platform. Observations revealed that there was a lack of structure to this storage, which resulted in difficulties in navigating

and finding the right material. This was a recurring problem during observations for both experienced and less experienced operators who spent time searching to find the relevant information.

The screw handling was identified as an important challenge in the assembly process. New screws were stored into a container, while unscrewed screws were placed on the table. These screws could often not be picked up purely by using a magnetic screwdriver bit alone, instead, the operator often had to use both hands to attach the screw and the bit the correct way. While the experienced employees seemed to perform the process quite fast, it was more time-consuming and difficult for inexperienced employees. The small size of the screws was challenging to handle, and inexperienced operators would not be able to handle them quickly. From the direct participation, this was confirmed to be tiring after doing this too much. Observations also showed that identifying the correct screwdriver bit was challenging. Operators were required to test multiple alternatives before finding the appropriate bit, which introduced interruptions in the assembly process.

Handling the electric screwdrivers was seen as a challenge for some of the most inexperienced employees. This issue was also brought up during a meeting with production employees. Maintaining a perfect vertical angle when installing the screws is essential as failure of this can lead to slipping and damaging a LED and thus resulting in quality issues. Since the screwdrivers hang vertically from a wire from above the workplace, they could easily deviate from their orientation. Having to constantly maintain the correct positioning required extra attention. This was particularly evident during the direct participation of inexperienced operators as this was clearly strenuous and fingers had to be used to guide the screwdriver correctly.

4.2.6 MTM-SAM analysis

Aggregated results from the MTM-SAM analysis are presented in table 8, showing possible theoretical and standard times for different parts of the process. However, different operators seem to use quite different methods. Some operators were indecisive, going back to the bill of materials (BOM), instructions or asking others for help with difficult details. The operator that was mainly observed for the analysis seemed to usually know what to do next, showing that the employee is experienced and thereby fulfilling the demand for performing time studies. Even the experienced operator demonstrated deviations from the presumed intended method though, given the lack of a true standard way of working. An example of this could be reorienting or moving parts on the table without it necessarily being required. After finding the theoretical times a 10% allowance factor is added, as done by Karim et al. (2016), generating the final standard times presented in table 8. To show how the analysis was performed, the full analysis sheet for getting and opening the product is attached in the Appendix.

Table 8. Approximate theoretical and standard times for parts of the assembly in seconds

Operation	Theoretical time	Standard time
Get and open the product	23.0	25.3
Add a driver	46.6	51.3

Replace the collar	157.5	173.3
Test and pack the product	62.6	68.9

The data in table 8 can be combined to create standard times for the full processes of adding a driver and/or replacing the collar, just like they are performed in the actual production. These results are presented in table 9.

Table 9. Approximate theoretical and standard times for full assembly processes

Operation	Theoretical time	Standard time
Add a driver – full process	132.3	145.5
Replace the collar – full process	243.2	267.5
Add a driver and replace the collar – full process	289.8	318.8

4.2.7 Assembly time data analysis

According to employees, the planned production times are based on some historical data, but they are not updated very often. Therefore, to get better data on the current setup and assembly times than the few cycles of video used in the SAM analysis, production orders with similar operations for Alpha are analysed to find the average constant and variable times. In the ERP system, orders are grouped based on the final product, but due to the recurring reworks at the company there are many possible ways for each product to be manufactured. To gather this data, the bill of materials (BOM) of each order must be checked for what components are added. As drivers and collars are the main components covered in the project, data is gathered for the processes of installing a driver, replacing a collar, as well as doing both things.

While the full process of adding a driver was below 4 minutes and the full process of changing a collar was recorded below 8 minutes when filmed, both with various losses, plotting order size and order time could reveal what influence each unit has on the total order time. In figure 22, the data for adding a driver, replacing a collar or doing both is presented in graphs showing the number of units in production orders and the number of minutes used to finish them. While a larger number of units clearly increases the time consumption, the relation between units and time varies among the orders. Plotting a linear trend line in the original data of the combined operation is problematic as the constant value becomes negative. Meanwhile, setting up the material and equipment for the combined operation could take longer than doing it for any of the individual operations as more material and equipment is needed. To get an approximate cycle time, the trend line is locked to (0,0) as a negative setup time isn't possible. If this is not done, the resulting cycle time may become longer than it should be.

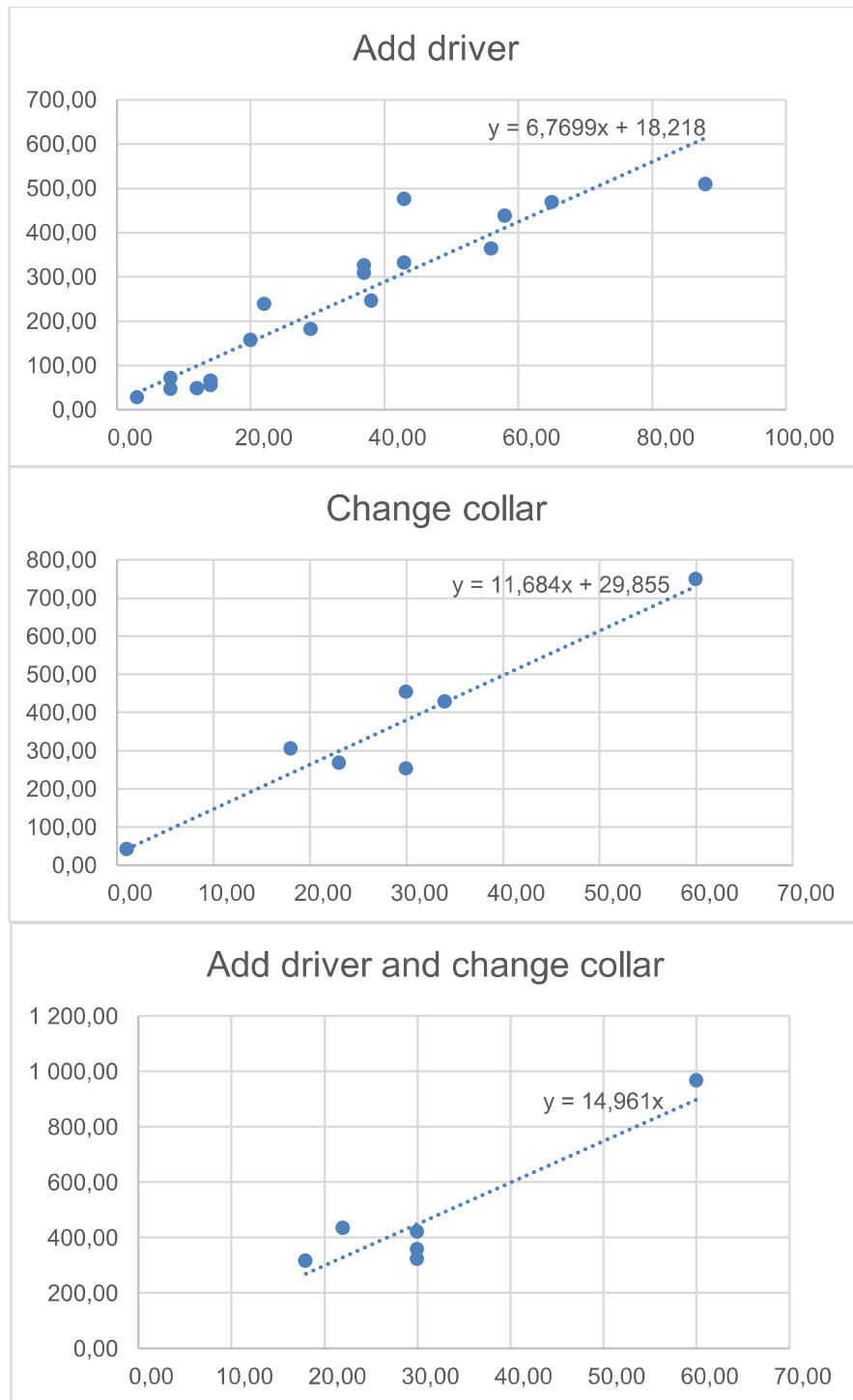


Figure 22. Production times plotted against number of units

Finally, the resulting setup and cycle times are presented in table 10. This analysis shows that the fixed times for Alpha assembly might be between 18 and 30 minutes, which also could be true for the combined operation as well even though no definite result was obtained for it. Given that this longer operation requires the most material and equipment, it likely has a setup on the higher end. By showing that the setups require many minutes to be performed, this quantitative analysis confirms the observations.

Table 10. Approximate setup and cycle times for the full assembly processes in minutes

Operation	Setup time	Cycle time
Add a driver – full process	18.21	6.77
Replace the collar – full process	29.86	11.68
Add a driver and replace the collar – full process	At least 20-30	14.96

With standard times determined in 4.2.6, they can be compared with the actual times to determine the current level of performance and utilization in the production. This is shown in table 11.

Table 11. Comparison between standard times and actual times in minutes

Operation	Standard time	Actual time	Performance and utilization
Add a driver – full process	2.43	6.77	35.83%
Replace the collar – full process	4.46	11.68	38.16%
Add a driver and replace the collar – full process	5.31	14.96	35.51%

The derived performance and utilization factors indicate that something might be wrong in the production, with an average percentage of 36.50% across the three operations. This could be a result of the observed variations in method, as workers who deviate from the proper way of working will require more time to perform the same tasks. Based on this result, an improvement in performance and utilization could potentially have a large impact on the practical assembly times.

4.3 Proposed assembly improvements

After collecting and analysing the data for the current state of the assembly, described in section 4.2, several improvements could be suggested. These improvements are primarily derived from literature but were validated through discussion with the managers, supervisors and operators at the case company, ensuring that the chosen improvements are realistic to implement.

One main difference found between the initial finding and the literature was that, in the literature, the importance of information support and work instructions during assembly processes was emphasized. While the manager from the case company indicated it was considered largely unnecessary since operators rarely use them during daily operations.

4.3.1 Proposed production approach

To better adapt to the customer lead time demands, more of the work could be performed in Sweden. Operations requiring significant manual work, which could include the pre-assembly of the body preceding the mounting of the collar, must be done in China for the foreseeable future as the cost advantage there is too large for doing it in Sweden. However, it is not known at the Swedish branch what work processes take place in China. Simpler assembly operations can be done in Sweden though, and some components could even be sourced locally. If products sometimes are

disassembled to make new combinations of body and driver box, one solution could be to have the two assemblies stored separately and combine them on demand. As mounting drivers and changing collars appear to be common operations, another option could be to add these components to the products in Sweden. A simpler solution could be to assemble all driver boxes in Sweden, while the bodies are still fully prefabricated in China.

The options of installing all drivers in Sweden and assembling the entire product in Sweden essentially represent short and long-term goals regarding the production of Alpha, which makes them both interesting for further analysis. One of the managers had even been planning to assemble more drivers in Sweden, but the idea had not been properly spread to other parts of the company. Given the immediate interest in assembling more driver boxes, the first goal for improving the production system would probably be improving this process. With the driver variable eliminated from the pre-fabrication variants, it might also be possible to start making products with a mix of transparent and opaque collars in China, reducing the need for collar reworks in Sweden.

More packing could also be done in Sweden rather than China, but several interviewees see a risk of high costs. While fully packing the pre-assembled products to subsequently unpack them and repack once finished is a quite evident loss, it is unclear how much there is to gain by not fully packing the assemblies from China. For this to be effective, the units must be much more compact when transported without the packing, and measures must be taken to ensure that they don't suffer any wear during the transport. In relation to the packing, there might not have to be labels on the individual boxes if none of the units from China are fully finished. Instead, there might only be labels on the outer box containing the individual Alpha boxes which is discarded anyways. This change would eliminate the initial step of removing the existing labels from the product box with a tool.

4.3.2 Material flow and layout improvements

Both proposed production strategies allow for certain components to take other paths through the operation than what they currently do. Interviews confirm that the material flow between the warehouse and the assembly is not completely optimal and that there are improvement gaps to fill. The current material supply is order-based, where material is delivered to the assembly area and then returned to the warehouse for each order. This suggests an opportunity to store drivers and other frequently used, smaller components such as metal clips and screws in an intermediate storage within the assembly area, rather than being delivered back and forth for every order. A suggestion is therefore to utilize the existing storage shelves available in the assembly area. This proposal could also include extending the existing replenishment principles to the Alpha components and improving material availability at the point of use within the assembly area. For the smaller components stored in boxes, a proposal could also be to implement a more structured two-bin replenishment method where material is replenished when needed, i.e. when a box is empty, instead of daily manual inspection.

Figure 23 illustrates a suggestion of an improved layout and movement patterns for the assembly-related processes. Observations revealed that the current material flow from the warehouse is transported around the production area before entering the assembly area. This indicates that there is an improvement opportunity to allow the material flow to flow a shorter path between the warehouse area and the assembly area. During a conversation with an operator and manager in production, the idea of moving some pallets was discussed. By moving a couple of pallets inside the warehouse and creating an opening to the assembly area, the transport distance can be reduced, see Process 1 in Figure 23. By moving materials within the same process closer together, movements can be reduced. For example, computers and printers, see Process 2, purple, which is the new route for this process. By moving material storage closer to the warehouse at the same time, materials can be transported over shorter distances, see Process 4, blue, which illustrates replenishment of the material storage. Process 3, orange, illustrates the operator retrieving all necessary materials to the workstation. By storing smaller material within the assembly area, rather than transporting them back and forth to the warehouse with each order, an entire process can be eliminated altogether.

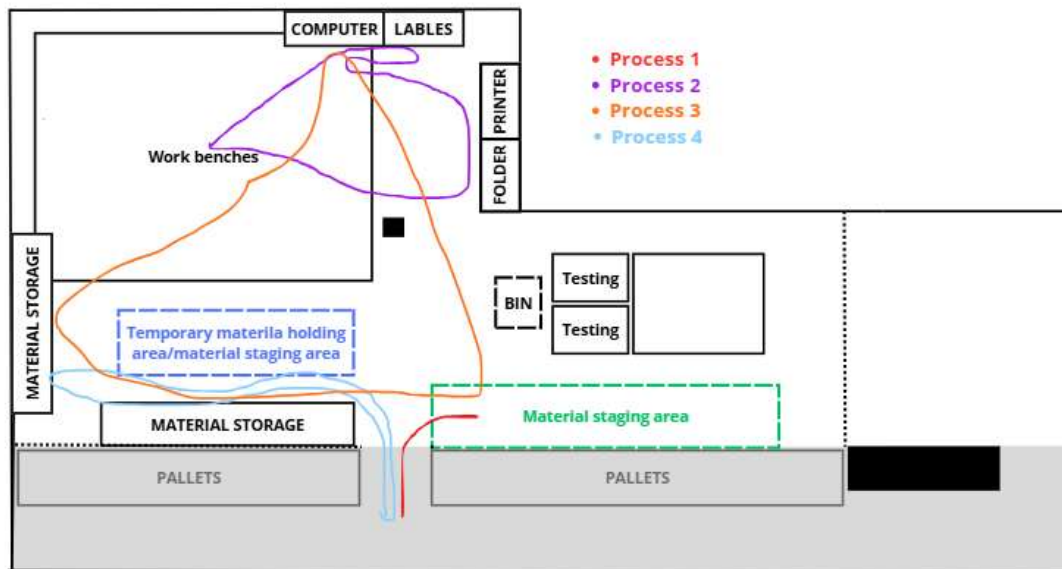


Figure 23. Spaghetti diagram of the suggested processes and layout.

The physical pillar placed at the workstation significantly limits the work area. Moving Alpha's work area to some other tables, which do not have this limitation, could have been a potential improvement that reduce unnecessary movements.

Collected material for orders were not always placed in their intended places according to operators. Sometimes empty carts could take up valuable space inside the work area, which in turn resulted in materials for orders being placed further away from the operator than intended. An improvement opportunity here is to establish a clearer and more standardized structure for the placement of materials and equipment. For example, a designated place for materials and empty carts should be defined to ensure consistent placement and efficient use of space.

4.3.3 Workstation and setup improvements

When printing labels, a time-consuming step was revealed where labels were printed and hung down in long strips on the floor, which then needed to be rolled up by hand by the operator. This suggests that there is potential to improve the management of this process. One suggestion is that a label rewinding mechanism could have been implemented to automatically roll these strips into a nice roll.

Materials were not always placed in their intended locations according to operators. Sometimes empty carts could take up valuable space within the work area which in turn resulted in materials for orders being placed further away from the operator than intended. An improvement opportunity here is to establish a clearer and more standardized structure for the placement of materials and equipment. For example, a designated location for materials and empty carts should be defined to ensure consistent placement and efficient use of space.

It was observed that tools were not stored in standardized positions during assembly. Although tools had designated storage locations, these were not within immediate reach, leading to operators placing tools in different locations on the workbench. A key part of the standardization is to have materials and tools as close as possible to the body, which one of the interviewees strongly recommended. This indicates an opportunity to improve tool availability and establish standardized tool placement that is within immediate reach, which could result in reducing the time currently required to search or reach for tools. This interviewee had seen the difference up close and witnessed a clear reduction in assembly time by doing this. During the observations, tools such as the cutter used to adjust the empty driver box for adding the driver or the screwdriver used to change the settings on the driver, were often placed so far away from the body that the operator had to reach for it. Keeping these items close, with standardized placements, should have a clear impact on productivity according to the interviewee and observations.

The challenge for operators in identifying the correct screwdriver bit indicates that there is potential for improvement in this process. Having to test multiple options before finding the right bit resulted in interruptions in the workflow. One improvement suggestion is to implement a tool identification system, for example in the form of colour coding where the bits are marked with different colours so that operators can quickly and easily identify the correct bit. This could have been further expanded by applying corresponding markings to screw containers in storage racks, enabling operators to easily match the correct screw bit with the appropriate screws. This proposed solution was presented and positively received by production personnel.

At the workstation, space on either side of it should be dedicated to raw material and finished products respectively, creating a flow from one side to the other. Then, to make sure that the materials are in a proper height, a pallet lifter with a high maximum height could be used. This type of equipment already exists at the

company, but a quite large, dedicated area will be needed for each pallet lifter to be used near the workstation. However, the table that is currently used for Alpha assembly does not have this kind of space available due to being blocked by a pillar, forcing the workstation to be moved. Below is an illustration of what this could have looked like, see Figure 24. Moving material closer to the workplace and the operator to reduce steps. With such a setup, the operator would have taken minimal steps while all material was within reach. Material is no longer placed behind the operator, the space around is instead more utilized.

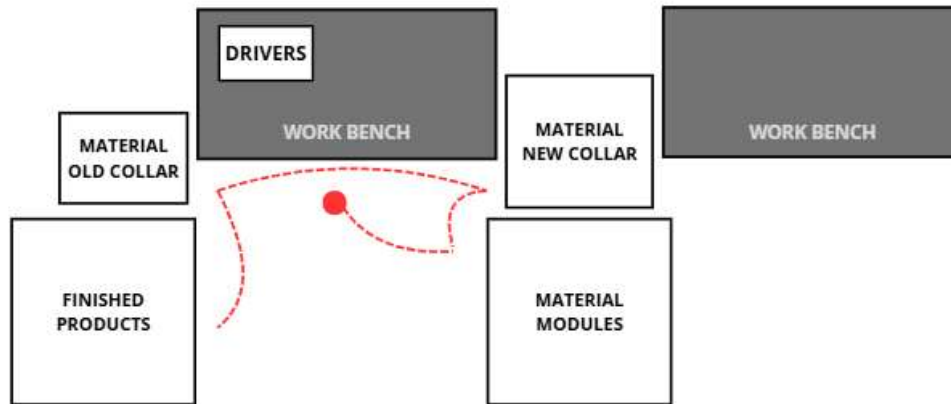


Figure 24. Illustration of the workplace with improved material placement for one operator.

In the case of direct participation, two operators worked in a flow and both workbenches were used instead. New material was placed on the far right and the old material and finished products on the far left, following a flow from right to left. Placing one operator at each bench and dividing the assembly process of the driver and collar between them.

Currently, 15 minutes are spent at the beginning of the shift and 15 minutes at the end of the shift on putting away materials that are brought back the next working day. An identified suggestion for improvement is to reduce the daily handling of materials for ongoing orders. For example, for orders that continue the next day, materials could be left at the workstation to a greater extent to reduce time waste and increase efficiency.

4.3.4 Work method improvements

As an initial measure, the workstation should be designed to minimize the time required to add a driver to an Alpha unit, given that this is the first step in moving production to Sweden. Improving material flows near the station is part of streamlining the work, but there are things inside the station that can be improved as well. The working method should be standardized, along with the placement of tools and components. This makes it easier for workers to remember what to do next, reducing the need to ask for instructions. The benefit of standardization was confirmed by one of the interviewees, making it a very relevant improvement. The standardized method also needs to be made clear through instructions.

It was observed that work instructions were not consistently available for all assembly operations. All steps should be included, with the most important steps in the process clearly stated in both text and images. Existing instructions could in some cases be unclear or incomplete. This resulted in operators relying on others or even performing tasks incorrectly. This indicates an opportunity to improve the accessibility and clarity of assembly instructions. Standardized instructions would need to be developed and made available at each station, either via a computer screen or paper format. These instructions would need to cover all assembly steps so that even inexperienced operators could easily follow them. This involves steps such as correct cable connections for driver configuration, as this was written down by hand by the operators, or correct product orientation, as this could be unclear. It was shown that digital instructions and related material were stored on a shared platform without a clear structure, making it difficult for all employees to find relevant information. This indicates an opportunity to improve how information is accessed as part of the working method. For example, materials and instructions could be organized in a standardized and structured way within the shared system, enabling operators to quickly find the information needed during the assembly process.

The issue of handling screws could be resolved with an automatic screw feeder, which presents screws in a vertical position, allowing a magnetic screwdriver bit to pick them up easily. Simultaneously, there are possibilities to mitigate the issue with handling the screwdrivers. An employee had looked at using an arm to hold the screwdriver in a fixed vertical orientation, perhaps allowing it to be moved around and used easily by the assembler. Another challenge identified as a time-consuming task during observations was the handling of screws and where they were stored during assembly. A suggestion for improvement to make it easier to present and handle screws is therefore necessary. For example, screws that are assembled away from products can be stored separately in boxes with markings such as “PCBA” and “collar” to distinguish them and store them in a safe place before they are assembled again.

To solve the problem of configuring drivers with small screwdrivers, a solution using fixtures was proposed at a workshop with production staff. The solution was presented as a fixture that has two functions in one, first to set all switches to the low setting and then to set the correct switch to the high setting based on the driver configuration. During the demonstration, this method appeared to be significantly faster but also more reliable. Especially for new employees because they no longer must learn exactly what the switch settings should be.

4.3.5 Analysis of the new method

With these proposed improvements, the new method can be determined and analysed with SAM to find the new standard times, presented in Table 12. As only small parts of the proposal were tried in practical experiments, the analysis is mainly a way of quantifying the theoretical impact of the improvements. The theoretical times for both current and proposed assembly processes are available in greater detail in the Appendix.

Table 12. Approximate theoretical and standard times for the new method

Operation	Theoretical time	Standard time
Get and open the product	13.0	14.3

Add a driver	42.7	46.9
Test and pack the product	58.9	64.7

These new standard times can then be compared with the current ones, in table 13. One important reduction is in the beginning of the process, where not having to walk as much, bend or remove a label saves around 11 seconds.

Table 13. Comparison between current and proposed methods

Operation	Current standard time	Proposed standard time	Reduction
Get and open the product	25.3	14.3	43.75%
Add a driver	51.3	46.9	8.49%
Test and pack the product	68.9	64.7	6.03%
Full process (sum)	145.5	125.9	13.47%

In this analysis, the full process of installing a driver gets a standard time of 125.9 seconds, which compared to the previous standard time of 145.5 seconds is a reduction of 13.47%. However, as previously seen in 4.2.7, the actual times are greatly influenced by the performance and utilization factors.

If the workstation is designed for this specific type of work though, the performance and utilization could possibly improve. It should be easier for workers to learn and remember the process if it is done in a standardized way, and they should perform better if they have the right aids. To predict the actual time, including performance and utilization factors, the current level of performance and utilization can be used. Then, in figure 14, predictions are made for what would happen if performance and utilization are improved with the new work design, and how big of an improvement it would be over the current assembly times.

Table 14. Predicted actual times for the full process of installing a driver

Performance and utilization	Predicted actual time	Reduction
35.83% (current)	5.86	13.47%
40%	5.25	22.50%
45%	4.66	31.11%
50%	4.20	38.00%
60%	3.50	48.33%

Ultimately, if the company manages to raise the performance and utilization by just a few percentage points when using the new work method, which should be very easy to achieve, assembly times could be shortened by at least 20%. Having the station constantly prepared for producing could significantly reduce the setup times, but there is no proper way of quantifying it. If the impact of standardizing work and improving the workstations is slightly larger, which seems likely based on the findings in 2.3 and 2.3.1, the times could perhaps decrease by 30% or even 40%. This means that labour related manufacturing costs could decrease by roughly the same amount, depending on what impact the improvements to material flows and setups have. This could be

achieved without forcing anyone to work harder, just by simply investing in the work design, allowing the work to be performed faster with a similar effort.

In the case that the new production approach would completely remove the need for changing collars, an alternative value for the improvement could be calculated. In this case, any order containing a change of collar is changed to an order where only a driver is added. Collecting the assembly times for all types of Alpha production in figure 25 reveals that the average cycle time across the three different processes is around 8.02 minutes.

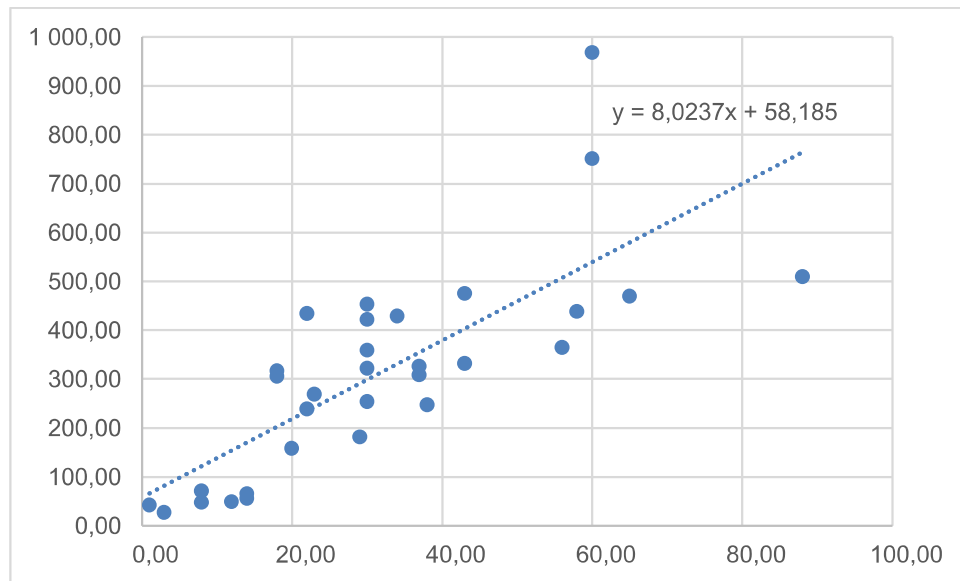


Figure 25. All ERP data from 4.2.7 in one graph

If this higher cycle time is used for the comparison with the proposed cycle times, the reduction also becomes larger. In table 15, the reduction immediately increases to 27% when having the current performance and utilization. If this combined performance and utilization factor is once again increased to around 45-50%, the reduction reaches 40-50%.

Table 15. Predicted cycle time reductions if no collars are changed

Performance and utilization	Predicted actual time	Reduction
35.83%	5.86	27.00%
40%	5.25	34.61%
45%	4.66	41.87%
50%	4.20	47.68%
60%	3.50	56.40%

Thereby, depending on how it is calculated, the reduction in assembly times could be 30-50% when implementing the improvements proposed in this thesis.

5 Discussion

This thesis examines how the productivity can be measured in the SMT line and final assembly, and how it also can be improved for the final assembly. Drawing on empirical data collected through observations, unstructured and semi-structured interviews, ERP and production management systems, the findings are discussed in comparison to the literature. The section is organized with one subsection for each research question in order, first discussing the data in the SMT line, then the current state of the final assembly, and finally the proposed future state of the final assembly.

5.1 Data in the SMT line

Not having quality data is a clear barrier to determining an OEE, with it being a key part of the larger KPI. However, figuring out the availability and performance seems to be what is most important for the company. While stop durations and patterns can be found, there is no way to efficiently collect stop reasons. Numbers are obviously generated when analysing the data, but its usage for making improvements remains limited without this context (Hedman et al., 2016). It could perhaps have been possible to observe more of the production and collect stop reasons manually during the research project, but it is not feasible to just have people observing the production in the long run. To solve this, the company could investigate improving the production management system so that it can collect stop times and reasons in an efficient way. One of the operators had experienced this kind of system at a previous company and thought it was a positive thing.

The results shown in 4.1.1-4.1.2 are not nearly as accurate as what would be generated by a specialized system. In particular, the resource statistics in 4.1.2 are very approximate due to being calculated manually. However, it is already evident through multiple data sources that setups take large amounts of time, something that could be valuable when planning production. If the batches are small too often, the company should try to minimize the setup times (Zhang et al., 2023), but if the planning transitions to larger orders, there might not be the same need for doing this investment. Regardless of the size though, the sequence of orders should always have setups in mind, given that transitioning between different products have different setup times (Vallada & Ruiz, 2011). In the end, the numbers and figures presented in this thesis show what knowledge could be gained by investing in a proper production management system.

Within the planned production breaks, there are supposedly up to 15 minutes of startup and 15 minutes of cleaning at the beginning and end of shifts. If using planned time to calculate the utilization, as described by Muchiri and Pintelon (2008), the analysis does not visualise the potential gains in reducing the time spent on these planned activities. A possible improvement discussed during the research project was to make a more dedicated shift handover, spending less time on cleaning and instead leaving the line prepared for continuing its order or beginning a new one. This allows the line to be active for longer, allowing more to be produced even if it isn't reflected in the utilization KPI. If the entire day is used to calculate the KPI, it could become a basis for transitioning into even more shifts.

Dividing micro stops and longer stops with a threshold of 5 minutes seems rather arbitrary, as different products have quite different theoretical cycle times. For example, during the project, cycle times ranging from 23 seconds to 90 seconds were found. With no precise definition though (Zennaro et al., 2018), the 5-minute threshold appears to be a valid approach. Perhaps, the threshold should be based on the theoretical time in some way, but this increases the demands on the future OEE system even more. Still, some stop sources might be missed if too many stops simply are labelled as micro stops. While this process of dividing stops into performance and availability losses could seem unnecessary, the analysis is aimed at showing the potentials of implementing an OEE system, in which case both performance and availability would be calculated.

The data shows that at least one of the machines in the line has a cycle time of around 34 seconds when manufacturing one of the products, so if many products have pick and place cycle times below this, those machines could be the bottleneck. If it is the other way around, the pick and place machine is the bottleneck. The bottleneck machines should be prioritized for improvement (Almomani et al., 2013), so future work at the company should try to determine where the biggest problem lies. While the OEE for the pick and place machine is lowered when it is bottlenecked, it should not be the subject of most improvements in those situations. However, the data in this project make it seem like the pick and place machine usually is the bottleneck, meaning that the results presented in this paper could be used to improve the efficiency of the entire production system.

Ultimately, the data in the SMT line has the potential to generate important insights for the management of the production. However, there is a need to implement system that properly determines availability, performance and quality could be implemented at the company. The manual analysis performed in this project probably cannot be done for every product and day, not only because it takes time from office personnel to perform it, but also because it takes time from the production personnel to gather the theoretical times from the machine. With a better digital system, more information could be extracted from the data with less effort. The lack of a quality KPI also serves as a clear barrier to determine the OEE, as quality is an essential part of calculating it. Unfortunately, given the subjective nature of the calculations in this research project, more work might be required to create the new system with Kechaou et al. (2022) arguing that the OEE and its three dimensions all must be properly defined. This positions the implementation of a new system for collecting and analysing production data as an excellent area for future work at the company.

5.2 The current state of Alpha assembly

The current production setup for Alpha reflects a hybrid production. Products that are delivered as finished products based on a forecast follow a make-to-stock approach, while semi-finished modules configured to customer requirements follow an assembly-to-order strategy (Harfeldt-Berg & Ohlager, 2024). According to Harfeldt-Berg and Ohlager (2024), the studied production environment reflects an uncertain and project-based demand, and the literature argues that the forecast-driven production therefore creates inefficiencies when the forecast and actual customer need

do not match. Interviews revealed repeated reworking of products to adapt to customer requirements, indicating that the current warning CODP may be positioned too far upstream in production. At the same time, the structure of the Alpha products mimics a modular structure where different variants can be created by combining standardized components such as bodies, collars and drivers (Lau et al., 2007). This modularity is visible in the current assembly process, where the production approach is mainly using this modular structure reactively through rework and component replacement instead of proactively through a more postponed production.

The material flow in the current production includes several non-value-added activities in the form of material handling and transportation. This was also visualized clearly in the spaghetti diagram in Figure 23. Needy and Bidanda (2001) highlight that efficient material flows should minimize interruptions, unnecessary transportation, and backward work. However, observations and interviews showed that materials were transported back and forth between the warehouse and the assembly area for each order. Operators also often walked back and forth to retrieve materials and set up the station. Materials could also be handled several times before reaching the intended assembly location. In addition, materials were transported around the assembly area despite discussions about opening a new connection to the warehouse to allow for a more direct and short transport route into the assembly. The intended material unloading is also located far from the warehouse, which contributes to longer transport distances. The following results indicate that the current material flow consists of several inefficient flows and activities according to Needy and Bidanda (2001). Furthermore, Petropoulos et al. (2026) highlight that material handling activities generate high labour costs when performed manually, making this even more important to minimize.

In the relation to the layouts described by Hasan et al. (2012), the Alpha assembly, and in fact the entire assembly, is in one sense organized as a functional layout. Different types of equipment are separated, for example with one area for materials and one area with workstations. These workstations can serve multiple purposes, aligning with the bench assembly paradigm described by Baudin (2002). However, this concept slightly transcends the layouts, as products now experience very little movement due to being built from start to finish in a single place, compared to the idea that functional layouts require high amounts of movement. Looking at the material flows, there are of course similarities to the conceptual model presented by Jonsson and Mattsson (2009), as should be for most manufacturing operations. While the single-station processes don't have internal buffers, significant amounts of material could in this situation be picked ahead of demand and placed in the production. This results in larger inventory costs but ensures that the production has the materials it needs (Petropoulos et al., 2026) (Jonsson & Mattsson, 2009).

The workplace organization showed that there was a clear structure on where materials and tools should be placed when the workplace is not in use, however, there is inefficiency during the assembly process. Materials and tools did not have standardized locations, which contributed to unnecessary time being spent searching

for or rearranging materials during the assembly itself. Observations also revealed that material pallets and finished goods carts were poorly placed around the workstation and behind the operator. Baudin (2002) argues that unnecessary movements are an important form of waste in assembly systems, while Hanson et al. (2018) argue that materials should be placed close to the body to minimize movements. The fact that materials and tools were not placed consistently during the work process resulted in unnecessary stretching, extra walking, bending and searching, which indicates a deficiency in both workstation organization and work design. Turunen and Almström (2024) further confirm this when they highlight that these types of movements are common work design losses in manual assembly. The current working method also showed that materials and workstations are reset at the end of each shift, even for orders that continue the next day. This creates a work environment that is organized, however, the results showed that operators spend time each day cleaning and moving materials back and forth.

Observations of operators revealed differences in assembly sequence, tool handling, and how uncertainties were handled during assembly. In the current situation, it was noted that operators relied on colleagues for support or information during the assembly activity, which indicates that the process is dependent on the transfer of experience-based knowledge between operators rather than standardized work procedures. Mor et al. (2019) believe that standardized work reduces variation and supports more repeatable work. The results therefore indicate that the current process is not standardized. A further interesting result is that managers within the company considered formal work instructions unnecessary and something that operators do not use. This is in stark contrast to Mattson et al. (2020) who argue that information support in assembly systems is important. However, observations and direct participation revealed that less experienced operators needed support or instructions during certain assembly steps. This is an indication that the need for instructions may depend on the operator's experience and the complexity of the task.

While Turunen and Almström (2024) list a set of quite simple basic motions when describing the SAM analysis, it could be argued that some motions in the assembly process of Alpha are too complex to properly quantify with these standard motions. Rather than just getting, putting and using items, the components and tools must sometimes be handled in slightly unconventional ways. For example, connecting the individual wires to the driver. Translating this complex reality into a correct SAM analysis may require someone with more experience to perform the analysis, a potential for future work at the company. Perhaps other predetermined time systems could be used as well to see which one fits the situation better. However, judging by what Turunen and Almström (2024) say about SAM being accurate and efficient to use, there might not be any significant potential in attempting to use other systems.

The assembly time analysis could not separate the performance and utilization factors when measuring productivity, even though they are central parts of the productivity concept for multiple authors (Heragu, 2023) (Almström & Kinnander, 2011) (Almström, 2013). This puts the analysis even further from the framework proposed by Almström (2013), where a total of five factors are used for performance and utilization. While losses were observed, it was not possible to quantify how much of

the total losses belonged to each category. Unlike the assembly times, which were calculated using all relevant ERP data, using only a few observed cycles of work to determine these losses would probably not give an accurate result. Finding a combined number for performance and utilization should of course be of use at the company, but the lack of detailed information might limit the potential of the result. Regardless, given that Clegg (2025) warns about variations in measuring productivity, simply establishing a way of calculating it at the company could have a positive effect.

The findings regarding performance and utilization could also allow the allowance factor to be questioned. Karim et al. (2016) states that 10% is valid in some situations but gives no way of determining situation-specific allowance factors. Getting a 10% addition could perhaps seem reasonable in high volume operations with efficient work environments, but in this case that allowance is probably too low. Aside from their personal time, workers might for example need time to handle materials throughout the work process, but this also depends on how the station is set up. Quantifying the need for allowances does not seem to be possible within the scope of this project, but given the very low performance and utilization found, increasing the factor by some percentage points could perhaps give a more accurate representation. Still, a more detailed analysis of the allowance needs could be a possible area for future work at the company.

To conclude, the current assembly is organized for low volume and high variety, with stations that aren't designed for any specific types of products. Materials are moved in inefficient ways, and workers often perform unnecessary motions. Without properly standardizing the work, employees often deviate from the best ways of working, resulting in work taking longer than it should. According to the calculations in this thesis, the speed of the work is only 36.50% of what it should be. Such a low number does however allow the methods for calculation to be questioned, specifically the addition of allowances.

5.3 Proposed improvements for the Alpha assembly

The findings from the current state analysis indicate that assembly-related costs are strongly connected to rework activities, material handling, workstation organization and unnecessary operator movement.

A crucial source of inefficiency is the recurring disassembly and reconfiguration of products that arise due to unpredictable forecasts. These disassembly activities in turn increase the number of handling and assembly operations significantly. This is because product customization is carried out before customer needs are fully known, which means that production is dependent on forecast accuracy (Harfeldt-Berg & Ohlager, 2024). Since demand is as uncertain as it is, with several project-based orders and varying volumes, Harfeldt-Berg and Ohlager (2024) recommend an assembly-to-order strategy. Increasing the level of postponement within Alpha's production flow could therefore reduce recurring rework operations. A suggested improvement would therefore be to only start importing modules from China and configure them according to customer needs and not take in any finished products. The modular structure of the Alpha products also supports this production strategy, as

(Lau et al., 2007) argue that modular product architecture enables delayed adaptation and flexible product configuration. Based on this, a more standardized modular approach can reduce the rework that currently exists. Another inefficiency identified in the results was the recurring exchange of transparent collars for white ones, solved by bringing in modules with both types of collars from China.

Disassembling products and assembling them again with other components takes too much time, especially in the case of changing the collar. It means that an unnecessary amount of work is performed on the products coming from China, creating an inefficient operation. Having body and driver box stored separately might, based on the design, result in more warehouse space being required. There are also many types of each part, so the number of different items in storage would still be high in comparison with the current situation. If both collar and driver are added in Sweden, prefabrication in China could be complicated as the collar is what holds the product together. This solution therefore works best if most of the assembly is done in Sweden. In theory, it could allow the PCBA to be sourced locally or possibly even manufactured in-house. Given the background of the project, performing a larger part of the assembly is the long-term ambition, but the productivity must improve significantly for this option to be viable.

The chosen option of adding all drivers in Sweden has a potential to reduce the number of prefabricated variants, as every size of Alpha has two driver configurations. The Chinese subsidiary would in this case need to manufacture all types of bodies, but not all types of driver boxes. While not really reshoring the assembly, this solution could completely remove the need to recombine driver boxes and bodies, as the driver boxes only would be finished on demand. Even though the time savings of eliminating these reworks are not quantified, it should be considered as an important improvement. Then, of course, given that the long-term goal is to manufacture even more of the product in Sweden, there is still a potential for future work.

One problem brought up during the interviews regarding packaging is that not fully packing the prefabricated Alpha units in China creates a new loss in the form of temporary packaging that must be disposed in Sweden. Currently, no such materials are removed from or added to the Alpha units from China. Then, of course, there should be additional costs for sourcing local cardboard and folding the boxes locally. However, as with the different parts of the Alpha, there should be benefits from moving value adding activities closer to the customer. Perhaps this is something to consider for future improvements following this project.

Assembling the driver box is, in theory, a short process, and if this were divided into multiple stations one could argue that the work becomes too repetitive. While the findings in 2.3 show extensive benefits with cell and line layouts, repetitive work would according to Botti et al. (2017) be negative for the company and its employees. The proposed production therefore initially remains a bench assembly, but many other things are changing. If more than the driver box is assembled in Sweden though, an assembly line would be relevant. The entire process of adding a collar and a driver should have enough length to be divided into stations, at least when testing and packing is included. Then, to adapt to the fluctuating demand, the staffing could

switch between WWAL and FWAL (Catalano et al., 2025), sometimes only having one worker on the line.

Regardless of what portion of the total work is performed in Sweden, there will be improvements to the material flows. The suggested layout and future-state spaghetti diagrams in Figure 23 shows that several transportation and movement activities could be reduced through increased use of material storage closer to the assembly workstations, grouping equipment together and moving material storage closer to warehouse. The proposal includes a reduction of material movement in the facility by simplifying the route from the warehouse to the assembly area, mitigating the loss described by Needy and Bidanda (2001). The current order-based transport of materials between the warehouse and the assembly area has been identified as a clear source of waste and needs to be improved Baudin (2002). A potential improvement could be the implementation of kitting, where the components used for an assembly cycle are grouped before assembly. Hanson and Brolin (2013) argue that search time and walking distances can be reduced and the presentation of materials is improved while unnecessary movements during assembly are reduced. Based on the challenges of the current assembly process, this could have been highly relevant and beneficial as operators spend a lot of time searching and moving materials. However, Hanson and Brolin (2013) highlight that kitting also introduces its own handling and preparation costs in the form of additional preparation, transport and handling activities to the kitting process itself, which must be considered. As the results revealed that Alpha has a variable and project-based demand with several product variations, there is also a risk that kitting can increase preparation activities and administrative work, as kitting needs to be continuously adapted to different customer orders and product variants. Hanson and Brolin (2013) therefore argue that assembly improvements must outweigh the extra resources required to prepare the kitting. In the current structure and production there is therefore a high risk that labour intensive activities are moved from assembly operations to kit preparation rather than eliminating waste completely.

Instead, point-of-use inventory storages may represent a more suitable improvement opportunity. Existing storage systems make it easier to implement a more standardized replenishment principle for Alpha materials. Implementing these replenishment principles can reduce transport between warehouses and assembly areas and place materials closer to the workstation. Huang and Kusiak (1996) highlight in their article that Kanban is a system that is based on actual consumption rather than on forecasts. According to Kanet and Wells (2019), the specific two-bin kanban system is particularly suitable for environments where low-cost components are frequently used that can be stored close to the workplace. A proposal is to introduce a more structured 2-bin replenishment system that could further reduce replenishment activities and daily manual checks. Kanet and Wells (2019) also mention that Kanban systems are visual and self-regulating systems that simplify replenishment activities and reduce the complexity of handling. This system could in turn have contributed to a more standardized workstation organization, which was seen as a weakness in the current situation, as operators can more easily collect materials in standardized boxes. The suggestion to leave materials for active orders at the workstation could reduce unnecessary material handling back and forth. This can

result in a reduce of non-value-added activities and free up time for assembly. Furthermore, if working methods become more standardized, it should be possible for other operators to take over the work in case of absence, for example, without having to take materials back and forth with each shift. This time could therefore have been spent on assembly instead.

While the flow is improved, the layout remains functional with bench assembly. However, both managers and workers have expressed interest in transitioning to a layout with dedicated material flows, for example cell or line (Hasan et al., 2012). If both drivers and collars are handled, the work could be divided. This was attempted during the direct participation, but other workers had also tried it. In that case, the production technician had observed a noticeable increase in the speed of the work, when not having to perform the entire process. With this information, a clear area for future work could be investigating if it is possible to transform this part of the production into such a layout. A prerequisite for this might be that a larger portion of the product is made in Sweden, but with the productivity improvements made in this research project, that could perhaps be possible in the future.

The workstation takes inspiration from the mixed-model assembly line concept, where different variants of a product are handled in the same place (Ebrahimi et al., 2022). In this case, there are three sizes of the product and four different drivers to be added. Due to the similarities among the variants, this proposal aims to fit all possible processes into the same station, using less space in the limited area of the factory. This ties in with the resources listed by Gianassi et al. (2025), where space is one of the five important categories. To account for the two resource categories performance and people, work design principles are used.

The new work design aims to mitigate the losses in the production. As mentioned in 5.2, unnecessary motions is one of the most important types of losses according to some authors, and it was therefore a key part of the development of the new work design. In this proposal, many tools and materials are moved closer to the worker to reduce the need for long stretches, steps, turns and bends. Doing this will improve the ergonomics of the work (Hanson et al., 2018). Importantly, pallets with prefabricated and finished Alpha units are moved to the immediate sides of the workstation and adjusted to proper height so that workers can interact with them more efficiently.

To support the proposed improvements in workstations and layout, the company should also implement a higher degree of standardized work within production. The current situation showed great variation between different operators regarding both the assembly process and other activities around it such as material handling. Mor et al. (2019) argue that standardized work creates clear and more repeatable work routines and reduces waste. Therefore, inefficiencies observed in the current assembly, such as material search, interruptions and inconsistent work methods, could have been reduced by implementing standardized procedures (Mor et al., 2019). However, standardization should not be considered as something that makes the work rigid or prevents future improvements. Mor et al. (2019) argue that the proposed standard should be the best method at a time that is managed as a guideline for improvements rather than a final solution. This is very relevant for Alpha production because Alpha products are so new that both volumes, variants and customer

requirements can change over time. Standardized work methods in the form of assembly and material handling could have simplified the evaluation of future improvements, since change proposals could then have been better compared against an identified current method.

The role of work instructions appears to be more complex and presents an interesting contrast between theory and practice. The interview results indicate that managers believe that work instructions are unnecessary in assembly work and something that will not be used. However, Mattsson et al. (2020) believe that assembly systems require information support adapted to both the work situation and the experience level of the operators. At the same time, observations showed that less experienced operators sometimes needed support, either by asking others or searching for information. The need for information support or work instructions exists, although it is not equally important for everyone. Rather than seeing instructions as a tool intended to guide experienced operators, they may instead be more valuable as support mechanisms during induction or training and less familiar tasks Mor et al (2019).

Based on these results, a suitable improvement would be to ensure that work instructions for the respective assembly process are available and that these are also adapted to new employees or operators with little experience, since the need exists here. Another improvement suggestion would be to instead of detailed instructions, have simpler and more standardized guidelines for critical assembly steps and product-specific configurations where ambiguity and uncertainty were often observed, even sometimes by experienced operators. Implementing such support could have reduced the need for other employees to help operators, which contributes to interruptions (Mor et al., 2019), while still allowing more experienced operators to work more flexibly during familiar assembly activities, which the company and managers find important. All information and documents for production should also be easily accessible and structured in a way that is easy to find. In today's situation, both inexperienced and experienced workers in production spend time searching for the right information.

When analysing the future state with the same framework as the current state, there appears to be no way to determine the performance and utilization factors. As Mor et al. (2019) indicate that standardized work improves productivity through multiple factors and Baudin (2002) indicate that workstations specialized for certain tasks make the tasks more efficient, the conclusion is that the performance and utilization should improve when the new method is implemented. With the observations that some workers use rather improper methods, an improvement is to be expected though. These findings show that there is a missing link between productivity and assembly literature, as improvements from the assembly literature cannot be easily analysed with predetermined time systems. Without knowing how much certain improvements affect production costs, companies cannot accurately determine if they should invest or not.

Employees did express possibilities of improving the product design for making the assembly easier. One example is the connector between the wall power and the driver, where operators add a label to know which wire is which, when this could just be printed on the connector itself. Another example is the pins in the driver box that must be removed to add the driver, which might not be needed if the driver is held in place by the metal clip itself. While this is out of the scope for the project, the observations confirmed that new employees might face many challenges with the current design. Given that design for assembly is an established concept (Battaia et al., 2018), this could be an important area for future work at the company.

During the research project, possible improvements within the organisation were also discovered. For example, communication between different parts of the company as well as the division of tasks between different parts of the company. Just like the design, this does not fit in the scope of this thesis and therefore becomes an area for future research. Something worth considering is lean production, where this thesis only uses lean tools related to material flows and productivity. Meanwhile, the full concept of lean production spans a greater portion of the company, including many organisational aspects (Jasti & Kodali, 2015).

In the end, the proposed method improvements are set to reduce the theoretical assembly time by 13.47%. With the current large deviation from the theoretical assembly times thought to be reduced, when combining the productivity framework in 2.1-2.1.1 with the theory in 2.3-2.3.1, the actual assembly times could be reduced by 30-50% when implementing the way of working proposed in this thesis. This calculation is based on what the times could be if workers aren't in any way forced to increase their effort, instead, this entire reduction is based on making the work more efficient. To accurately determine if there is a basis for requiring specific workers to increase their effort, standard times must be calculated in the right way with the right allowances. The low performance and utilization factors should therefore not necessarily be interpreted as any evidence for employees working too slow. All time required to be spent outside of the assembly method must be properly quantified, or workers might be forced to surpass 100% in effort to achieve the new target productivity. The improvement may of course not be instant, as workers have to learn the standardized method. Immediately aiming for a high performance and utilization could result in a too large change in the way of working.

This reduction in cost can be used as a facilitator for assembling all driver boxes in Sweden, reducing the tied-up capital that Jonsson and Mattsson (2009) describe as an important source of costs, while also allowing a wider range of customer needs to be met with the prefabricated units. If the inventory of prefabricated units can be used to create more variants, then perhaps fewer reworks will be needed. With the many types of positive effects that the proposal potentially has, quantifying them all becomes a too large task for this project. A potential area for future work could therefore be to analyse the situation at the company from a more general operations and supply chain perspective, determining the larger scale implications of offshoring and reshoring certain products or parts of products. Such a project could also determine if there are more products that can be partially or fully reshored, something that could be of high

interest if the ways of improving productivity presented in this thesis start being implemented throughout the operation in Sweden.

6 Conclusion

In this thesis, the operation at a Swedish luminaire manufacturer was studied. The two areas of interest were the SMT production and the final assembly, where RQ1 included analysing data from the SMT line, RQ2 included understanding the current state of the final assembly, and RQ3 included proposing a future state of the final assembly.

In the SMT operation, data was found that showed each time the machine produced a PCBA, allowing the cycle times to be calculated. The theoretical cycle times were also found, allowing them to be compared with the actual times to calculate the KPIs. To separate the micro stops from the longer stops, a threshold of 5 minutes was used. Then, the availability could be calculated by using the longer stops, while the performance could be calculated by using the short stops. The availability of the studied production ranged from approximately 50% to 80%, where the lowest availability occurred in a situation with many setups. Meanwhile, the performance in these cases ranged from approximately 60% to 80%, with the lower performance coming from the pick and place machine being bottlenecked by another machine. When multiplying these two KPIs, the sum ranged from approximately 40% to 60%, indicating what the OEE could be. This analysis shows that significant potentials for improvement exist in the SMT production, creating a foundation for future research, improvement and investment at the company. Importantly, these findings indicate that it could be valuable for the company to improve the production management software.

The study further showed that the Alpha assembly line is organized as a high-variance, low-volume assembly process, with workstations consisting of flexible benches. The current production strategy consists of a combination of make-to-stock and assembly-to-order, where prefabricated products are produced based on forecasts and later reworked according to customer needs. Since demand is uncertain, this creates recurring rework activities. Inefficiencies related to material handling, non-standardized work organization and unnecessary operator movements were also found. Material flows consisted of repeated back-and-forth transports and multiple handling activities. All materials were, for example, materials are order-based and are thus transported back and forth between the warehouse and the assembly station for each order. Operators performed unnecessary walking, stretching and searching torque during assembly work. The workstation was very organized when not in use, but during assembly a lack of standardized material placement was revealed, which contributed to a constant search that takes time and unnecessary movements. The production process relies more on knowledge transfer between operators rather than work instructions, which may explain variations between operators and non-value-added activities within the assembly process.

Based on the identified inefficiencies that exist in the current situation, there are several improvement potentials that can reduce time and thus assembly-related costs within Alpha's assembly process. Increasing the postponement of product differentiation until customer requirements are known, assembly-to-order, could

reduce the recurring rework and improve the flow that exists in the current production. In addition, there would be an improvement opportunity to import products with white collars as well, instead of only transparent ones, which would have reduced unnecessary collar changes during assembly, which today took the longest. Additional improvements identified are in material handling and workstation organization. Implementing a Kanban system for inventory management at the workplace would in turn have reduced unnecessary transport between the warehouse and the assembly area. By opening a new connection to the warehouse and creating an alternative shortcut, materials can also be transported a shorter way from the warehouse to the assembly area, which also reduces unnecessarily long transports. The results also suggest that increased standardization of work methods could reduce process variation and create more stable assembly procedures. By standardizing the workplace and placement of materials during the assembly process, by placing tools and materials closer to the operator and in specific places, both the search time for materials and tools, ergonomic loads, unnecessary movements for the operator and the assembly time can be reduced considerably. While experienced operators rarely use instructions, there was a need for less experienced ones. In summary, the study shows that a reduction in non-value-adding activities and improvement of the material flow represent important opportunities for reducing labour-related costs and assembly inefficiencies.

The thesis has limitations but provides opportunities for future research. The findings are based on a single case in electronics industries, and thus, generalizability beyond the case could be investigated through adding more cases or surveys. The thesis also focused on productivity without assessing its impact on, for example, financial aspects. For productivity improvements to facilitate reshoring at more companies, the reduction of manufacturing costs and its impact on the company must be more thoroughly studied.

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Appendix

Productivity improvement equations

$$Productivity = M * P * U \quad (1)$$

$$Productivity = M * P_P * P_S * U_N * U_S * U_D \quad (2)$$

OEE equations

$$OEE = Availability * Performance * Quality \quad (3)$$

$$Availability = \frac{Operating\ time}{Loading\ time} \quad (4)$$

$$Performance = \frac{Theoretical\ time}{Operating\ time} \quad (5)$$

$$Quality = \frac{Approved\ amount}{Produced\ amount} \quad (6)$$

SAM analysis sample

[illegible]

Figure 26. SAM analysis of the initial parts of the assembly process

Detailed theoretical times for the assembly process

Table 17. Theoretical time in seconds for detailed parts of the process of adding a driver

Operation	Current theoretical time	Proposed theoretical time
Bring the product to the table	7.6	3.2
Remove labels and open the box	7.7	2.0
Unpack the product and separate it	7.7	7.7
Prepare the driver box for adding the driver	15.7	15.5
Add the driver and the metal clip	8.5	6.1
Screw the driver into place	6.1	5.0
Plug in the wires to the driver	10.1	10.1
Add covers to the driver	6.3	5.9
Add labels to the driver box and body	7.4	7.4
Connect the driver box to the body	7.4	7.4
Connect the testing equipment and start test	5.9	5.9
Add labels to the box	6.5	6.5
Disconnect the testing connections	8.6	8.6
Put the product in the box	11.9	11.9
Add manuals and close the box	9.4	9.4
Store the finished product	5.6	1.8

