BACHELOR THESIS

INCREASING THE PRODUCTION OUTPUT OF KVADRAT SHADE

IEM THESIS

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kvadrat shade

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PREFACE

Dear reader,

I would like thank several individuals who have helped me with the completion of this thesis.

First and foremost, I would like to extend my sincere thanks to my University of Twente supervisors, Dr. Niels Pulles and Dr. Ipek Seyran Topan. Your constant guidance, feedback, and support have been invaluable throughout this process. You have always steered me in the right direction, and for that, I am very grateful.

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Ahmed Saadawy

University of Twente

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MANAGEMENT SUMMARY

This thesis was conducted at Kvadrat Shade Assembly (KSA), a company based in Eibergen, the Netherlands, which produces roller blinds. Established in 1963, KSA has become known for its innovative metallization process that enhances the energy efficiency within spaces using their blinds.

Over the years, KSA's demand has been steady, as their main customers are based in the Netherlands. With the desire to grow, KSA plans to expand into the DACH (Germany, Switzerland, Czech Republic) region and into the UK market. With this expansion, they believe that they must be able to produce 60.000 rollers blinds per year. Therefore, the primary goal of this thesis is to identify and implement cost-effective strategies to increase the production output of KSA to 60.000 roller blinds per year. Although KSA believes that they are capable of producing 30.000 roller blinds per year, a capacity study was first done to verify this number. The central research question guiding this thesis is: ***"What are the best ways for KSA to successfully scale up their roller blinds production to 60.000 per year, by reducing their production inefficiencies, while seeking low-cost approaches?"***

The capacity study revealed that KSA are capable of producing 27.870 roller blinds per year. After identifying the current production capacity, the production processes at KSA were observed in order to identify the issues leading to a smaller production outcome than what is needed. It was concluded that the biggest issue leading to the failure of meeting future demand was the excess production inefficiencies within the production process of KSA.

To understand these inefficiencies, the current processes at KSA were observed more, specifically in terms of the impact on the production process due to the different roller blind variants that KSA offers. The analysis also differentiated between project and retail orders, revealing that project orders, which account for around 67% of the annual demand, are significantly more efficient. It became apparent that the larger and more standardized project orders facilitated smoother and faster production flows compared to the smaller and more customized retail orders.

Following this analysis, a systematic literature review was done, which was needed to provide a framework for this research to follow. A review of Lean Manufacturing offered insights into waste categorization, value-adding versus non-value-adding (NVA) processes, and different tools to tackle the identified wastes. These tools include single minute exchange of dies (SMED), 5S, and many more. Key concepts from the Lean Manufacturing philosophy shape the approach of identifying and addressing production inefficiencies at KSA.

Using the principles of Lean Manufacturing, the production process at KSA was observed and analyzed again, timing the process for both project and retail orders. This was done with three observations, which helped pinpoint specific inefficiencies within the production process. Using the times of the processes and the definition of NVA processes, for each workstation, the production times were categorized based on value adding and NVA processes. Using the NVA process, five production wastes were identified at KSA:

1. **Material Handling**: Inefficient movement and handling of materials.
2. **Employee Walking Paths**: Excessive walking by employees due to suboptimal workstation layouts.
3. **Startup Inefficiencies**: Delays and inefficiencies during the startup phase of production.
4. **Cart System**: The current cart system for transporting materials is inadequate.
5. **Fabric Changeover Time**: Significant downtime during fabric roll changes.

This analysis also revealed that the fabric cutting table is the slowest process at KSA, which creates the limit of the output to 27.870 roller blinds per year.

Based on these findings, several solution approaches were developed and analyzed, each targeting specific inefficiencies within the production process, and utilizing the Lean Manufacturing framework. These included redesigning workstation layouts to reduce worker movement, implementing optimized cart systems to enhance the internal transport of materials and products, and making improvements in the fabric cutting process, such as adjusting fabric roll changing procedures or investing in automatic fabric changers. Additionally, the feasibility of adding extra shifts and better utilizing existing but unused infrastructure was evaluated. These solutions are:

1. **Sawing Workstation Layout Redesign**: Reorganizing the layout to improve material flow and reduce worker movement.
2. **Packaging Workstation Layout Redesign**: Optimizing the positioning of packaging materials and finished products to minimize movement.
3. **Cart System Optimization**: Implementing Automated Guided Vehicles (AGVs) to enhance material transport efficiency.
4. **Using Unused Infrastructure**: Utilizing existing but unused tables through hiring additional employees to increase production capacity.
5. **Fabric Roll Changing Adjustment**: Implementing a fabric changeover table to reduce downtime during fabric changes.
6. **Automatic Fabric Changer**: Considering the investment in an automatic fabric changer for long-term efficiency gains.
7. **Adding an Extra Shift for Fabric Cutting**: Maximizing the use of existing infrastructure and labor by adding an extra shift.

Since fabric cutting is the current bottleneck, the fifth solution immediately increases the roller blind output to 34.217 per year, hence it is the first recommendation to KSA. However, to achieve an output of 60,000 roller blinds, the solutions must be combined.

The second recommendation to KSA involves purchasing three cart pushers, hiring one more employee for material gathering, adding a second shift for the fabric cutting table, implementing the fabric changeover table, and changing the layout of the packaging workstation.

The third recommendation to KSA includes the same recommendations as the second, with the addition of hiring one more employee for material gathering, assembly, packaging, and bubbling workstations, and changing the layout of the sawing workstation.

The three recommendations are presented in the table below:

Solution	New Production Output	Cost of Implementation (EUR)
Solution 5: Fabric roll changing adjustment	34.217	1.000
Combination of solutions: 1, 2, 4, 5, and 7.	45.176	102.702 per year + 11.996 initial investment
Combination of solutions: 1, 2, 3, 4, 5, and 7.	60.631	222.702 per year + 12.220 initial investment

An implementation plan was then developed based on the proposed recommendations. The plan was phased to ensure a smooth transition and to minimize disruptions to the ongoing production. The first recommendation should be implemented immediately to quickly boost production capacity. The second recommendation should be executed within the upcoming two years to further enhance production capabilities as demand increases. Finally, the third recommendation should be in place by the end of 2029, anticipating that the demand will reach 60,000 units by 2030. This phased approach ensures that KSA can incrementally improve its production efficiency while managing costs and resources effectively.

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1. Introduction

The first chapter introduces the bachelor thesis assignment, which consists of a company introduction in **Chapter 1.1**, followed by the problem identification in **Chapter 1.2**, where a core problem is selected. Finally, **Chapter 1.3** discusses the main research question and the sub-research questions.

1.1 Company Description

Kvadrat Shade Assembly (KSA), located in Eibergen, the Netherlands, is a leading manufacturer of roller blinds and pleated blinds, shown in figure 1. Founded in 1963 by Cornelis Verolme, the inventor and founder of metallized textiles, KSA specializes in producing blinds distinguished by their innovative metallization process. This process, conducted at Kvadrat High Performance Textiles (KHPT), involves applying a thin layer of aluminum to fabrics, reducing the need for heating and cooling by making the fabric highly reflective.

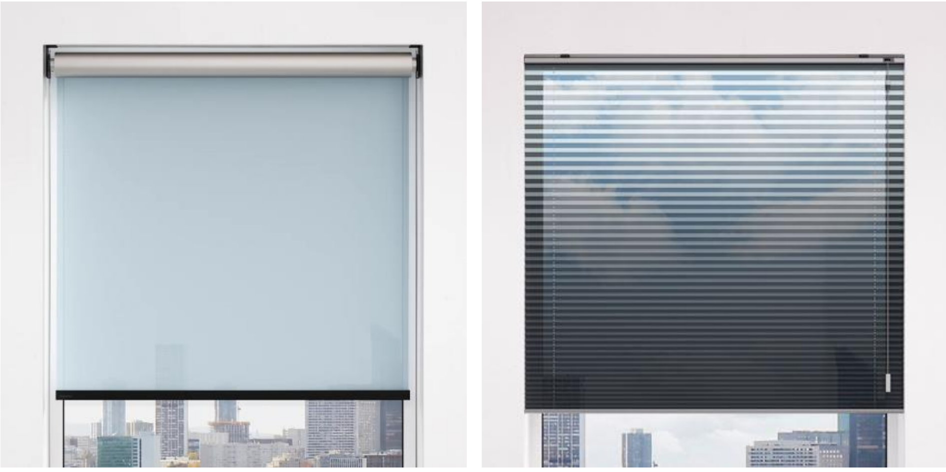


Figure 1: KSA Roller Blind (Left) & Pleated Blind (Right). Adapted from kvadrat.dk

KSA and KHPT were previously one company known as Verosol B.V., until they were acquired by Kvadrat Holdings in 2019. Today, both KSA and KHPT operate as separate entities under the ownership of Kvadrat Holdings. KHPT produces and sells normal and metallized fabrics to various manufacturers, including KSA. 25% of KHPT's sales are directed towards KSA's production of blinds. **This thesis is done for KSA.**

KSA's production facilities span 3.500 square meters, including 15 workstations, a repair area, and two warehouses. With approximately 100 employees at KSA and 1.000 Kvadrat employees globally, KSA are dedicated to delivering high-quality blinds to their customers. In 2023, KSA achieved sales totaling 11 million euros.

Although KSA sells two different blind types, the roller blinds and pleated blinds, each type of blind comes in various profiles, sizes, and colors. According to KSA's sales data of the last three years, roller blinds account for 60% of the total sales and pleated blinds account for the remaining 40%.

This thesis will focus solely on the production of the roller blinds. The production process of the roller blinds takes place in eight of the 15 workstations. Figure 2 below highlights the main steps taken in these workstations to produce the roller blinds. The first step for the roller blinds production is where all the metal profiles are cut. Different roller blind models have various profiles, including a tube, bottom profile, main profile, and side profiles. After the sawing, the fabrics are cut to the specified size, then glued to the aluminum tube. If the order requires the fabric to be pocket welded, then it goes through the welding station, otherwise, it moves directly to the material gathering station, where the employees gather the necessary tooling needed per order and then assemble the roller blinds by hand. Then, the blinds get inspected, bubble wrapped, packaged, and sent off to the customers.

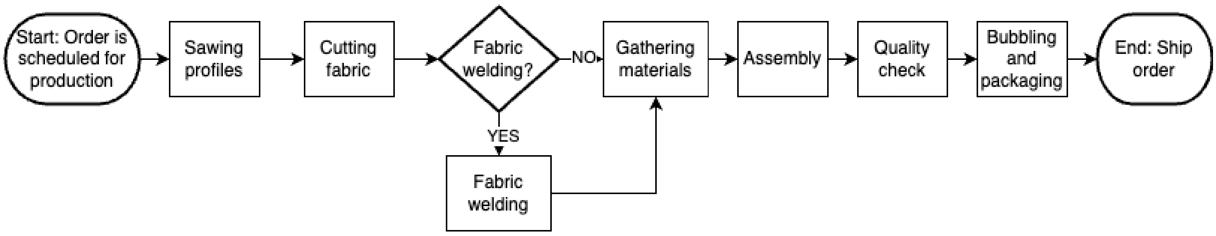


Figure 2: Roller Blind Production Process Flowchart

1.2 Problem Identification

This section of the thesis discusses the context of the problem presented by KSA, followed by an analysis on the given problem to identify the causes leading to it.

1.2.1 Context of Problem

Most of KSA's sales are currently made in the Netherlands, which has seen steady demand over the last two years. In 2022, KSA sold 25.190 roller blinds, then in 2023, they sold 25.090 roller blinds. Because of the steady demand and KSA's desire to grow, they plan on expanding into the DACH region (Germany, Austria, and Switzerland), and into the UK market.

For KSA to expand into both these markets, their production facilities must be able to increase production output. The current estimated yearly production capacity of KSA is 30.000 roller blinds, and they anticipate that they must be able to produce 60.000 roller blinds per year to accommodate for the new expected demand. Although KSA believes that they are capable of producing 30.000 roller blinds per year, a capacity study is first done to confirm that, since this number is an estimate.

For a company to increase their production output, some investments need to be made. For example, investments could be made in labor costs if more workers are needed to be hired or in new machines. On the other hand, there could be benefits to increasing production output, such as an increase in sales and revenue, utilizing economies of scale, or gaining a competitive advantage. Since Kvadrat acquired Verosol, management decisions on new investments have been stricter. For the first time since acquiring KSA, Kvadrat made a loss in 2023, which has made them much more reluctant to spending on new projects and ideas. Moreover, with the rise of climate awareness, Kvadrat's budget for the next years is planned to be spent on sustainable solutions, as they have a goal of reaching 100% carbon reduction in 2030, and going net zero in 2040 (Kvadrat, 2024). Although there could be benefits to increasing production, Kvadrat is currently prioritizing short-term profitability over long-term investments due to their tight budget constraints. For these reasons, there is a budget constraint with regards to upscaling production.

The issue KSA is facing is that they are unsure of how to increase their production output while considering budget constraints. After discussing the budget constraint with the managing director at KSA, they stated that if the investment required to increase production output is reasonable, as in, the production output increase relative to the price is worth it, then the solution could be considered. Due to the high variety of roller blinds at KSA, there is no data available over the profit per product, which is why profit per extra product produced cannot be evaluated.

1.2.2 Action Problem

The problems stated in the previous section lead to the following action problem: The production team of KSA would like to upscale their production capacity of roller blinds from an estimated 30.000 to 60.000 products per year but is facing financial challenges and is therefore seeking low-cost options to do this.

After exploration of the action problem, a deeper analysis is conducted to find the essence of the problem, through a problem cluster. Figure 3 displays this problem cluster, which visualizes the interconnected problems within KSA by mapping them, along with their connections (Heerkens & Winden, 2017, p. 42).

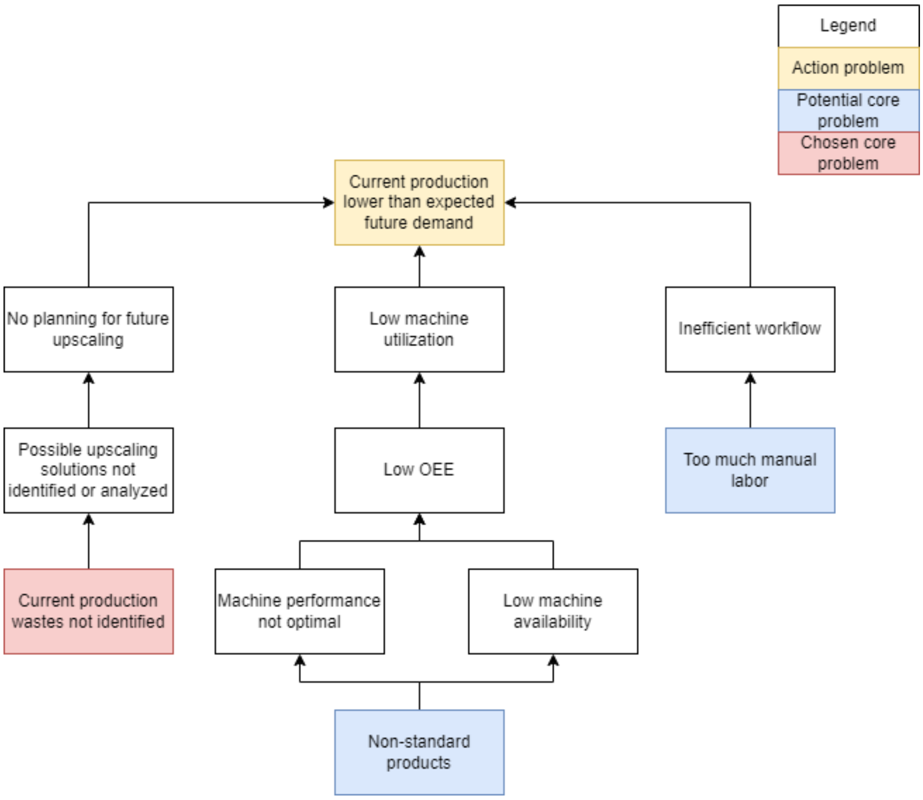


Figure 3: Problem cluster

To come up with the problem cluster, a list of problems were first made. These problems were found through observation of the production process and interviews with some stakeholders, including the production manager and the managing director. The problems were then connected based on cause-and-effect relationships, in order to identify the core problem which would also solve the action problem.

1.2.3 Core Problem Selection

Given the causal chain from figure 3, three core problems lead to the action problem. Of these three problems, only one is chosen as the focus of this research. The other two problems could be addressed indirectly as an outcome of solving the chosen core problem, however they are not addressed directly. The problems are:

1. **Too much manual labor**

   Production processes which produce products with a high volume are usually partly or fully automated. By being automated, every part of the system is then specialized to create one aspect of the final product, at a much faster rate than if it were done by hand (Bihler, 2022). Since KSA highlights quality as their core principle, each product is made and checked by hand, leading to excess manual labor. This potential core problem cannot be influenced; hence it is not the chosen core problem (Heerkens & Winden, 2017, p. 44).

2. **Non-standard products**

As aforementioned, KSA sells their roller blinds in different colors, profiles, and sizes, leading to lost time when adjusting machines, especially for the fabric cutting. This lost time reduces the overall equipment effectiveness (OEE). OEE is a product of quality, availability, and performance (Slack & Brandon-Jones, 2019, p.371). The cause of the reduced OEE is from the performance loss and low machine availability. This potential core problem is not the focus of this thesis, however, increasing the production capacity could indirectly increase the OEE of the fabric cutting table.

3. Too many production inefficiencies

From observing the production process, many production inefficiencies were identified, and that was only after observing the first workstation in detail. A lot of the observed inefficiencies were caused by excess movements which could be reduced at a low cost, making the current process more efficient. Some of the identified excess movement in the first workstation could be eliminated from machinery movement or better preparation. Since KSA has a financial constraint, fixing the current problems which cause the production output to be lower than the norm is the priority. From there, the new production output can be increased further by purchasing new machines for the workstations or hiring more staff, for example. Moreover, KSA do not have the best track-record with identifying inefficiencies and making the right decisions with respect to solving production problems that hinder the output. Last year, an extra machine was purchased for the ninth workstation, the inspection area. This machine is still wrapped in its box and has never been used. For a company that is having financial constraints, purchasing this machine was not a wise decision, however, this assignment could potentially utilize this extra machine. KSA's management team has put an emphasis on this problem, and it is the most important problem from the problem cluster (Heerkens & Winden, 2017, p.44). Solving this problem will also solve the action problem, which is why it is chosen as the **core problem** that this thesis will focus on. The production inefficiencies are to be described in detail in the fourth chapter, the problem analysis.

1.2.4 Core Problem

The chosen core problem is: **Too many production inefficiencies**

Because of the budget constraint, it is in KSA's best interest if the method of upscaling production is financially viable. To come up with a financially viable solution, a capacity study will first be done, to have an understanding of the current bottlenecks in production. Following this study, it will be more clear which workstations in production hinder the production process and include inefficiencies which could be removed or reduced.

Two crucial aspects which are affecting the production flow at KSA are the number of roller blinds ordered per order and the high variety in roller blinds that are sold. **There are two types of orders at KSA, project orders and retail orders**. Both of these orders impact the production flow, which will be discussed in detail in the coming chapters. However, it is important to note that project orders are classified as any orders with more than 25 roller blinds ordered, and retail orders are any orders with 25 or less roller blinds ordered. Figure 4 below shows the number of roller blinds ordered per order in 2023. It is used to visualize and illustrate the distribution of order quantities in KSA.

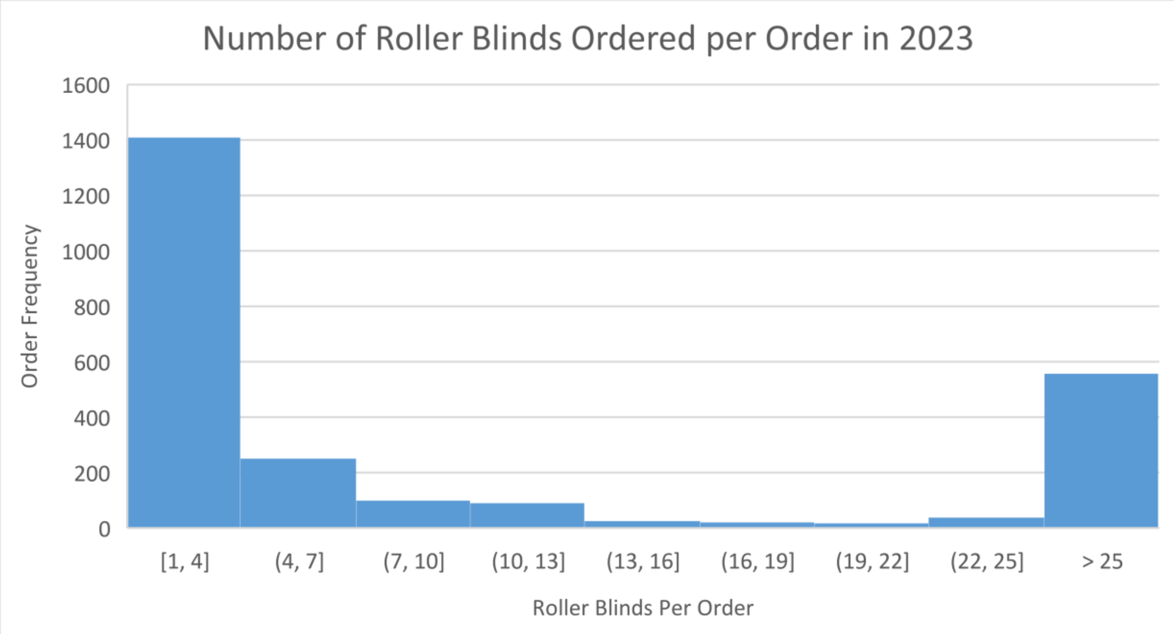


Figure 4: Histogram For Number of Roller Blinds Ordered Per Order. Adapted from Microsoft AX [Computer software]

As can be seen from the figure, of the 2.505 roller blind orders in 2023, 434 orders were project orders, accounting for a total of 16.666 roller blinds of the 25.090 produced roller blinds. Although the number of project orders is almost six times lower than the total number of orders, they account for about 67% of the total roller blinds produced within KSA, so it is important to include this figure when coming up with a recommendation for KSA to follow.

Moreover, the extensive range in roller blinds that KSA produces also impacts the flow of production. Currently, there are over 11.000 stock keeping units (SKUs) at KSA, since there are 59 different roller blind variants, and many more fabric colors and models. However, at the end of 2024, KSA will phase out one of their roller blinds range, the Verosol collection, so there will be a total of 29 roller blind variants at the start of 2025, and a lower number of SKUs. Figure 5 below shows the roller blind variants along with their sales percentage for the years of 2022 and 2023.

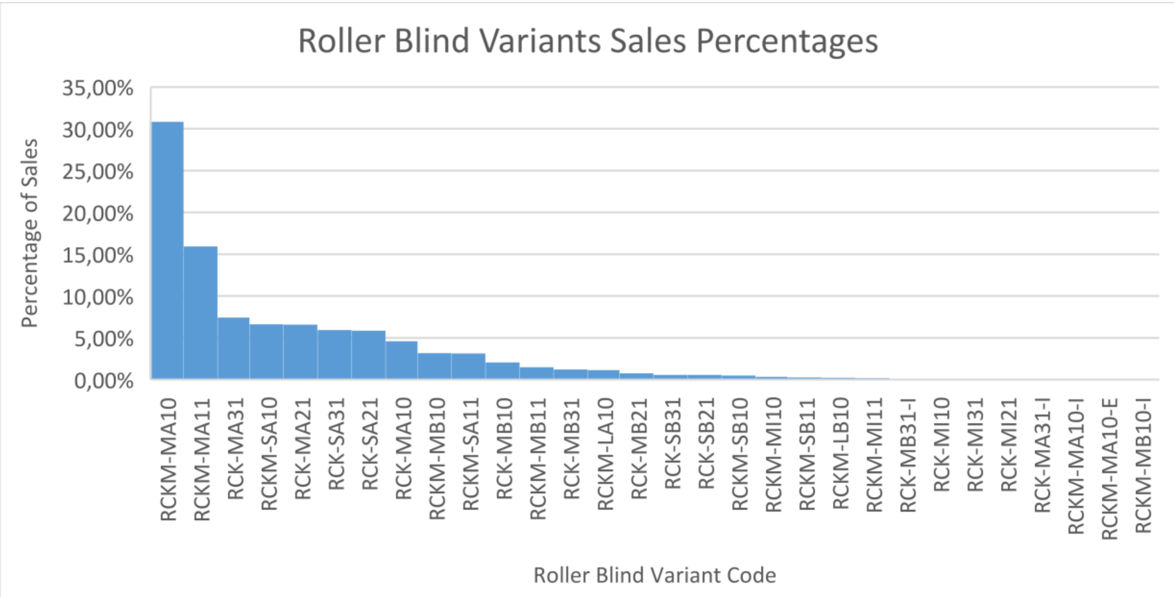


Figure 5: Histogram Depicting Sales Percentage Per Roller Blind Variant. Adapted from Microsoft AX [Computer software]

As can be seen from the figure, the three left most roller blind variants account for more than 50% of the total sales of KSA. Understanding these sales percentages is crucial for increasing production output, since **currently, the KSA team believes that the high amount of roller blind variants causes problems in production. However, this thesis will help KSA see through this problem.**

The strategies for upscaling production should consider the complications which arise from KSA having two different order types and 29 different roller blind variants (2025 onwards), ultimately enhancing production efficiency and capacity to meet the future increased demand.

1.3 Research Questions

This thesis is structured in seven different chapters, with the goal of coming up with recommendations for KSA to increase their production output by decreasing their production inefficiencies. A research question is made which needs to be answered to reach the research goal.

The following is the main research question:

"What are the best ways for KSA to successfully scale up their roller blinds production to 60.000 per year, by reducing their production inefficiencies, while seeking low-cost approaches?"

Furthermore, sub-research questions based on the main research question are developed to break down the problem into smaller parts. The sub-research questions shape the format of this essay, as they will be addressed in different chapters.

The sub-research questions are shown in table 1, along with the chapters in which they are addressed.

Table 1: Sub-research Questions with Subsequent Chapters

Sub-research Question	Chapter Addressed
1. What does the current roller blind production process look like at KSA, and how are the different roller blind variants and order types addressed in this process?	2
2. What are the biggest sources of production inefficiencies at KSA according to the findings from the literature, and what is the current production capacity at KSA?	4
3. What are the best ways to deal with the identified production inefficiencies?	5
4. What production benefits can be derived from addressing the issues identified in the previous question, and what additional improvements are necessary to reach the target production output of 60k roller blinds per year?	5
5. What are the best fitting recommendations that can be made to KSA based on the results of the previous chapters?	6

2. Current Processes at KSA

The aim of this chapter is to give an overview of the current situation at KSA: on how roller blinds are produced, and on the impact on the production process from the different order types and roller blind variants. Doing so answers the first sub-research question: *"What does the current roller blind production process look like at KSA, and how are the different roller blind variants and order types addressed in this process?"* **Chapter 2.1** outlays the roller blind characteristics, followed by an overview of the portfolio range of the roller blinds at KSA. Then, **Chapter 2.2** discusses the process of producing the roller blinds at KSA. Following that, **Chapter 2.3** describes how different variants in orders and roller blind types are addressed in production at KSA. Finally, **Chapter 2.4** summarizes the second chapter.

2.1 Roller Blind Variants

This section discusses the different roller blind characteristics and variants. Understanding the roller blind characteristics is crucial since a lot of the roller blind terminology will be used throughout the report.

2.1.1 Roller Blind Characteristics

Each roller blind model has 'obligatory' parts, but there are models which also include additional parts. Figure 6 below shows one of the many roller blind models which exist, a model with a closed cassette, which highlights different characteristics of the roller blind. This model will be referred to when explaining the different parts of the roller blinds.

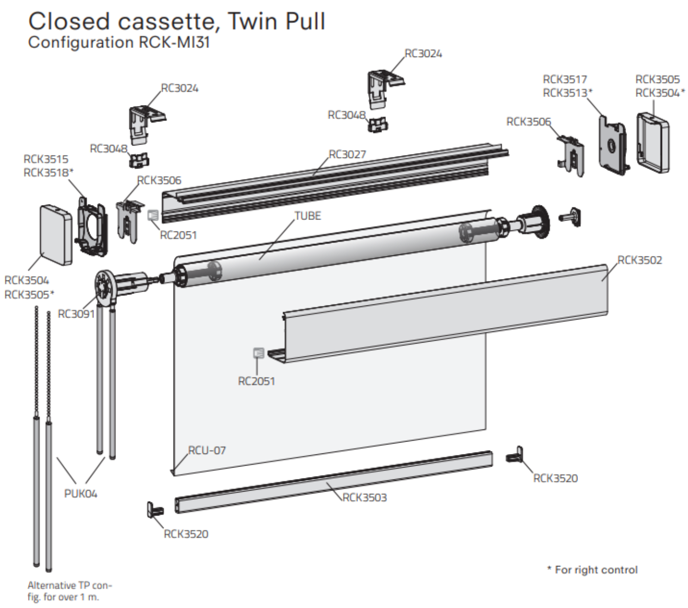


Figure 6: Roller blind Showcasing Product Characteristics. Adapted from The Kvadrat Shade 2024 Prijslijst

The 'obligatory' parts

These are the parts which every roller blind variant includes, as they are essential for holding up a blind. The obligatory parts include:

1. **Tube:** Always at the top of the roller blind. The tube is what spins to move the fabric up and down. It is also what holds the fabric. The fabric is held to the tube using a special type of tape.

2. **Bottom profile:** The bottom part of the blind which allows it be balanced when hanging. Highlighted as RCK3503 in figure 6. The bottom profile is where the logo of KSA sits, on the side.
3. **Fabric:** Connected to the tube from the top and the bottom profile from the bottom. It can also be connected with the side guides. Highlighted as RCU-07 in figure 6. The fabric size determines the size of the roller blinds, which determines the size of profiles which must be sawed.
4. **Mechanism of moving the blind:** Connected with the tube. Can be either a chain, motor or twin pull. Highlighted as RC3091 and PUK04 in figure 6.
5. **Brackets:** The small parts which hold the pieces together. An example is RCK3517 in figure 6.

The rest of the parts

These parts are in different models, they are considered to be "extra" options for the roller blinds. They are added for both appearance and functionality purposes:

1. **Side guide:** Could be a cable side guide or profile side guide. Makes the roller blinds more stable. Side guides are placed on the sides of the fabric. It is optional for a customer to add, but required for certain width to height fabric ratios. Any ratio higher than 1:3 requires it.
2. **Installation profile:** Used for roller blinds which need to be attached to a ceiling, rather than being mounted to a wall.
3. **Cassette:** Can be both closed and semi-open. Figure 6 has a closed cassette, parts RC3027 and RCK3502 are joined together to create the closed cassette.

Throughout the report, the word **"profiles"** is used, and that refers to the tube, bottom profile, side guides, installation profile, and the cassette.

2.1.2 Roller Blind Portfolio Range

Currently, KSA has two roller blind portfolios within their range of products, the Kvadrat Shade and the Kvadrat Verosol portfolios. The Kvadrat Verosol portfolio will be phased out at the end of 2024, so this section will only highlight the Kvadrat Shade portfolio. In the fourth chapter of this thesis, the Kvadrat Verosol portfolio will be highlighted by shifting over the demand of the roller blinds from the Kvadrat Verosol portfolio over to the new Kvadrat Shade portfolio.

Within the Kvadrat Shade portfolio, there are two ranges of products, namely the "Minimal Bracket" and the "Bouroullec". **The difference between these two ranges is merely in the design.** To highlight the degree of customizability for the roller blinds at KSA, figure 7 shows the options which a customer must choose from when placing their order for the roller blinds.

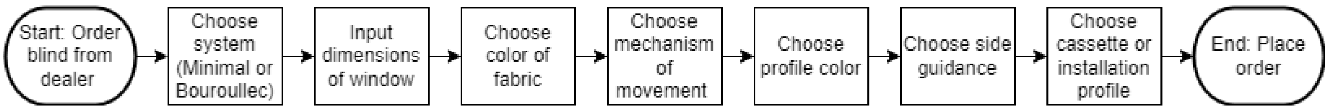


Figure 7: Customer Ordering Process

Combinations of both the Minimal Bracket and Bouroullec systems along with the mechanism of the movement, whether there are side guides or not, and whether cassettes or installation profiles are installed, have made a pre-fixed 29 different models at KSA. These models are all identified with different code names. The way the models are named is shown in appendix A, with an explanation under it. Moreover, appendix B includes tables which show the full product portfolio for the Kvadrat Shade range, the Bouroullec and the Minimal Bracket.

As stated, the degree of customizability at KSA is very high. There are currently 59 different pre-fixed models of roller blinds, which will be reduced down to 29 at the end of 2024. Moreover, there are 36 different fabric colors, which come in two types, metallized and non-metallized. There are also five transparency levels for the fabrics, totaling **360** different fabrics. Furthermore, the fabric can be customized in the roller blinds order. Customers can choose to have the bottom part of the fabric in the roller blind welded, as shown below in figure 8, adding an additional step in the production process.

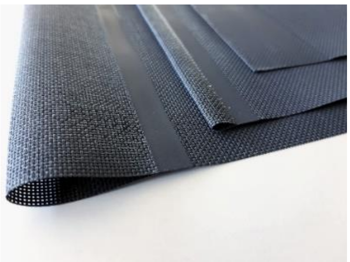


Figure 8: Roller Blind with Pocket Welding. Adapted from Maticmachines.com/en/products/welding-4/hera-39.htm

2.2 The Production Process

This section describes the production process that the roller blinds go through at KSA by describing the general process of the production, followed by a detailed process per workstation at KSA.

Production is planned weekly at KSA by analyzing the amount of available work hours during the week and filling them depending on the time taken per order and the orders due date. Production starts once a production order is planned on a certain day. The bill of materials (BOM) are printed by the production planner, who sends them to the production employees on the morning of production, and sends them to the material gathering employees a day in advance to the production. The roller blinds are produced daily, and if the production orders planned for the day are not complete, they get pushed back to the next working day, as work-in-progress (WIP).

Figure 9 shows the current production layout of KSA. This layout includes the roller blind and pleated blinds workstations, therefore the focus is only on workstations 1, 2, 4, 5, 7, 9, and 11.

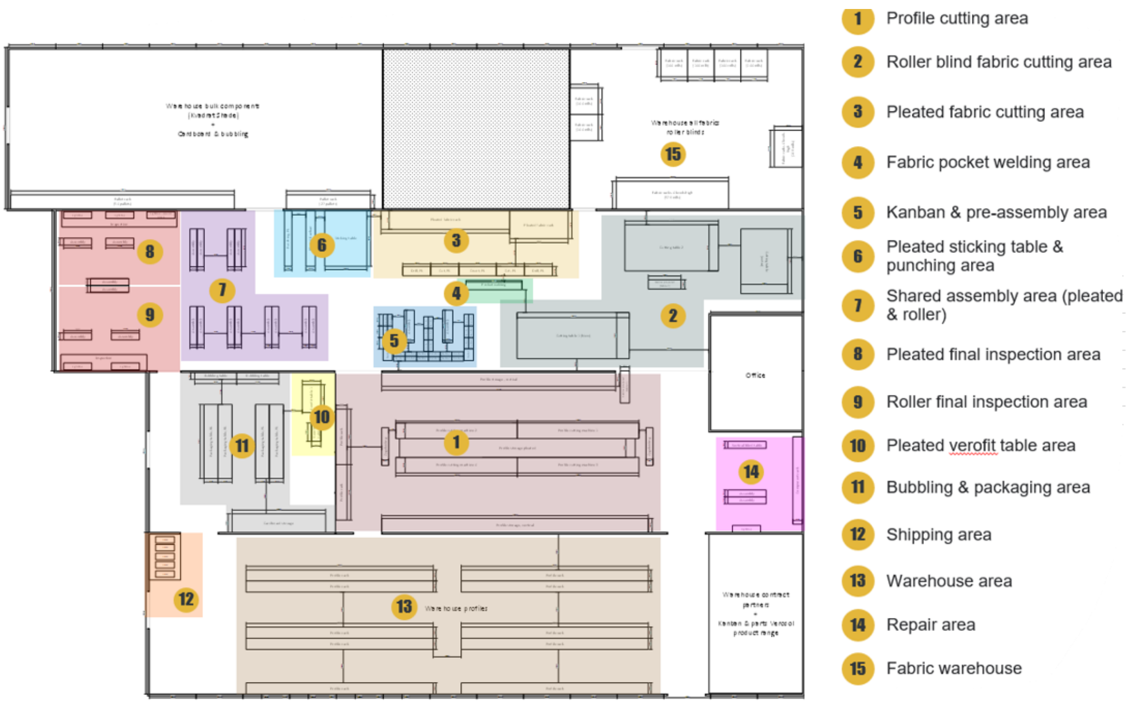


Figure 9: KSA Production Facility Lay-out. Adapted from Kvadrat Shade Assembly

In the production facilities of KSA, parts are moved from one workstation to the next using carts, shown in figure 10 below. The cart system works as follows: The BOM is placed on one of the 12 cart racks, and after each part for the roller blind is ready, it is placed on that rack. For example, after the sawing in workstation one is done, the sawed parts are placed on the cart, and then moved to the fabric cutting area. After the fabric is cut, it is glued by tape to the tube, and is also placed on the cart, and moved to the next station. The carts are emptied at the packaging area, where the packager takes the completed blind from the cart and then wraps it. The cart system is used to prevent the parts of the roller blinds from being misplaced or lost, since each part for each roller blind is unique with regards to the size, depending on the order.

Figure 10: Cart System for Moving Products/Parts KSA

Now, the detailed production steps per workstation are discussed.

Workstation 1: Profile Cutting

The first workstation is a shared area between the roller blind and pleated blind production. There are a total of four sawing machines, which are divided equally among both types of blinds. The sawing process starts with the employee reading the BOM and printing stickers for each part to be sawed. They then walk to the area with the empty carts, pick up a new cart, and walk it back to a working table close-by to the sawing machine. After that, they read through the BOM, which includes the materials required for each step, with the measurements for sawing. The employee then must walk to a wall which holds the metal profiles that need to be sawed. One by one, from this wall, the employee collects the required materials for the order and then walks back to the sawing machine and places the materials on the sawing machine feeder to start sawing. Before sawing, the employee inputs the cutting measurements in the computer of the sawing machines, and then saws the profile. This is done by scanning a barcode from the BOM into the sawing computer. After sawing each profile, the employee uses an air blower to remove sawing residue from the sawed parts using air pressure. Then, the stickers which were printed earlier are stuck onto the sawed profile, which are then placed on the cart. If the part being sawed is the bottom profile, then the employee walks to the laser machine, which engraves the logo of KSA on the side of the bottom profile, and then walks back to their working table. Finally, the employee walks the finished cart to the fabric cutting station.

The parts which need to be sawed are depending on the order, but include: tube, bottom profile, side guides, cassette’s, installation profiles. Moreover, some customers request their side guides to be drilled rather than glued to the tube and to the bottom profile, so the sawing employee drills holes on the side guides after sawing it.

Workstation 2: Fabric Cutting

The fabric cutting phase includes two steps. The first step is cutting the fabric required for a roller blind, and the second step is sticking the fabric onto the sawed tube.

Cutting the fabric begins with the cutting table employee taking the BOM from the carts which already have the sawed parts on there. They then see the fabric required for the batch they will produce. The fabric, in a form of a roll, is placed close to the cutting table on racks by the warehouse workers the day before the production. The cutting table employee finds the fabric needed for the current order and places it on the cutting table fabric feeder. This is done in four steps, firstly, the employee locates the fabric, then they walk to a special vehicle nicknamed “the giraffe”, drive the vehicle to the required fabric roll, pull it out and put it on the fabric feeder at the cutting table.

Normal sized fabrics are handled by “the giraffe” which is parked close to the cutting table and the fabric inventory area. Otherwise, if the fabric is in the form of a jumbo roll (100 meters or longer), a special structure holds it, and an extra tool is used to pick it up. The fabric cutting table employee then inputs the measurements on the computer of the cutting table, which pulls the fabric onto the cutting table and starts to cut horizontally and vertically simultaneously. The fabric table is capable of cutting fabrics with a maximum width of 317cm, and height of 585cm.

Once the fabric is cut, the employee moves it to the end of the table to another employee. From there, the fabric is stuck onto the sawed top tube, which already has the strong tape on it. Finally, the employee places the finished parts back onto the cart and moves it to either the fourth or fifth workstation, depending on whether the order requires fabric pocket welding or not.

Workstation 4: Fabric Pocket Welding

Fabric welding is done using a welding machine, which uses high heat to weld the fabric together. In this workstation, the fabric welding machine employee grabs the roller blind from the cart, and then they pick up the bottom part of the fabric, welding it to a higher part by using the welding machine.

Workstation 5: Materials Gathering

The fifth workstation is an area with many storage units which have the rest of the parts needed to assemble the roller blind. It consists of shelves, boxes, and a table. This step is done a day before the production process of an order starts. The employees pick up the required parts such as the brackets or the rope used as a mechanism for moving the roller blind. After picking the parts up, they place them in a box and indicate the steps they have taken by updating the Kanban board. Then they keep the boxes with the roller blind parts on a table close to the seventh workstation, such that the employee from the seventh workstation can quickly identify the box needed during the next working day.

Workstation 7: Roller Blind Assembly

The seventh workstation consists of six tables for the assembly of the roller blinds. In this step, the employee has all of the required tooling on the tables, and they assemble the full roller blind. Each roller blind variant has its own instructions to follow, and each variant has a different assembly time, as they have different assembly steps. Since the assembly employees are experienced, they do not need to follow the instruction manual most of the time. Although there are six available tables for assembly, currently, two are used with a maximum of three when it gets busy.

Workstation 9: Quality Inspection

In this phase, the almost complete roller blind is moved by cart from the previous workstation to the inspection area. The inspection area currently has two employees and stations which are working, with a third one available but not installed yet.

If the roller blind is motorized, then the inspector assembles the motor. All motors are assembled here, except the 230v motor. The inspector then checks each roller blind individually. The roller blinds are placed on a vertical moving rack which pulls them up. If the roller blind is motorized, then the inspector also programs the motor to stop the roller blind movement at the right height. Moreover, there is a strong light box which produces light similar to that of the sun, allowing for the inspector to inspect the fabric as if the sun is shining through it. After the inspector places the roller blind on the machine and pulls it up, they check the fabric with their eyes, carefully checking whether there are any defects. They also check the mechanism of moving the blinds, ensuring that it moves smoothly. Finally, they ensure that the roller blind is balanced, so that it is not tilted on any sides. If all of the checks pass, then the inspector places a sticker on the roller blind and puts the blind back on the cart. After inspecting each roller blind in the cart, the cart is then moved to the eleventh workstation.

Workstation 11: Bubbling

Bubbling takes place in workstation 11. Although bubbling and packaging take place in the same workstation, both processes have separate tables and employees. In this phase, the roller blind is bubbled to avoid damage in the packaging. Moreover, if the ordered roller blind includes a 230V motor, then these motors are also bubbled in this step, but they are not programmed.

The bubbling station currently has one employee working there, while there are two tables available for bubbling.

Workstation 11: Packaging

The final workstation is where the finished roller blinds are packed within boxes. The packaging employee takes the bubbled roller blinds from the carts, then places them on the packaging table. They then walk to the cardboard box storage area, bring the cardboard back to the table, and make the box from the flat cardboard piece. After that, they place the roller blind in the box, and walk over to a machine which fill small plastic bags with air. These bags, which will be referred to as “airbags”, are then put on top of the roller blinds in the packaging to protect them. Finally, the packaging employee scans the BOM to notify the production team that the order is ready, prints some shipping stickers, and closes the box with the stickers. After packaging the roller blinds, the packages are placed on pallets close to a door, where they are picked up by the couriers. There are currently three tables which could be used for packaging, of which, two are being used.

2.3 Addressing Variety in Production

This section explains how KSA are currently addressing variety in their production processes. The variety includes variety in roller blind models and variety in order types.

2.3.1 High Variety of Roller Blinds

Through observation of the production processes at the facilities of KSA, some findings were made. The first finding is the fact that most roller blinds with a larger width size take a longer time to produce. The second finding is the excess changes in the fabric roll at the second workstation in production, because of the nature of the customizability of the roller blinds. The final finding is that all roller blind variants follow a similar path in production, but take different amounts of time to produce. These findings are all currently addressed by the production planner.

The size of the roller blinds impacts the production throughout the whole process, but the most noticeable workstation that gets impacted is workstation two, the fabric cutting. Through observation, it is clear that the machine employees are much faster at dealing with smaller fabrics, and that the cutting machine is capable of cutting smaller fabrics at a much faster pace, highlighting the efficiency associated with smaller-sized blinds. Also regarding the fabric cutting workstation, the production planner has less cutting options for the fabric when the roller blind sizes are larger, resulting in higher fabric waste with larger fabrics (two or more fabrics can be cut simultaneously if the size allows and it is for a project order). Moreover, in the final two steps of the roller blind production process, the bubbling and packaging, it is much easier to handle smaller roller blinds, as the bigger roller blinds require more time and care when packaging and bubbling them. To further show the impact of the roller blind sizes on the production times, figure 11 below highlights the production times for the same roller blind variant, in three different sizes. The average increase in the production time per size category, from the example presented in figure 11 is 7,56%.

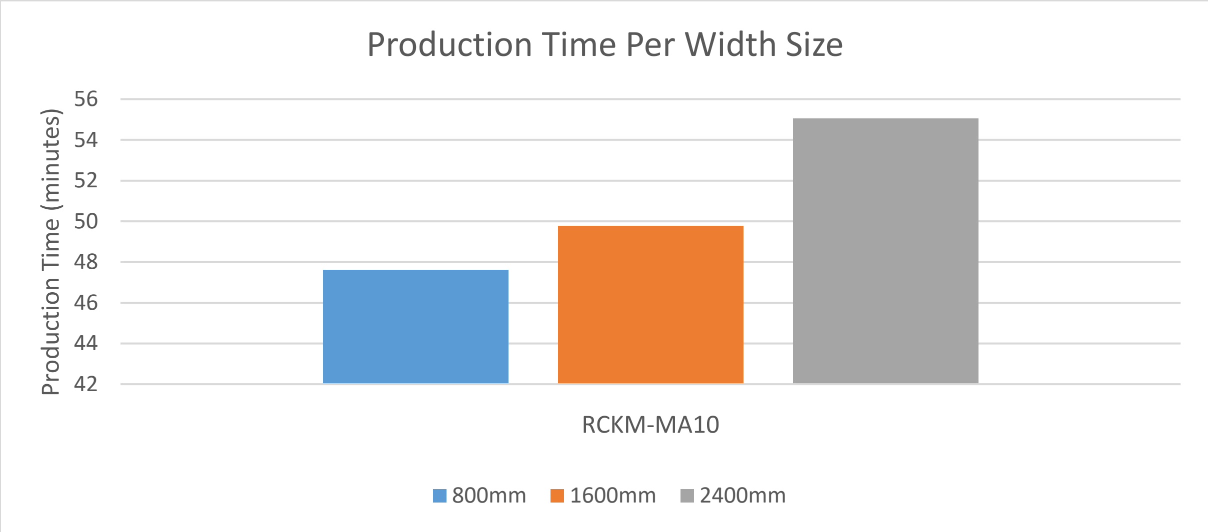


Figure 11: Production Time RCKM-MA10 Per Size Increase (Width). Adapted from Microsoft AX [Computer software]

Moving on to the second finding which impacts the production processes at KSA, due to the high number of available roller blind fabrics to choose from (360), there are frequent fabric roll changes between production runs. This reduces the availability of the fabric cutting machine. There are on average 62 fabric changes per work week for the fabric cutting machine. Moreover, if the customer orders a roller blind with a specific fabric that is only made in jumbo rolls, then it creates challenges for the fabric cutting employee as they must invest additional time and effort into handling these bulkier fabrics, thus slowing down the cutting process even more. It takes an average of 20 minutes to change a jumbo roll, compared to 5 minutes for a normal roll.

The final finding impacting the production processes at KSA which comes as a result of the high variety of roller blind variants is the different production times for each roller blind variant. The detailed production times per roller blind are addressed in the fourth chapter, however**, it is important to highlight that although the roller blinds have different production times, these times are quite similar to one another. Moreover, all of the roller blinds follow the same production steps** (except if fabric welding is required). The only difference between the models is that at some workstations, extra steps are required. For example, some blinds require more profiles to be sawn at the first workstation, which is why they take a longer time to produce. Similarly, some blinds require a motor to be installed, which is done at the inspection workstation, while others use a pulling system, which is then done at the assembly station.

All of these observations are addressed by the production planner during the planning phase. As aforementioned, the production planner plans the production runs weekly, by looking at the available hours of production and the number of hours needed for production to avoid delivering the roller blinds late. The enterprise resource planning (ERP) system that is used at KSA, Microsoft Dynamics 365, contains the expected production time per order. It takes into account the size of the roller blind based on previously made orders, and the roller blind variant. So, for the production planner, they use this data when coming up with the production schedule.

2.3.2 Different Order Types

Section 1.2.4 identified the two order types, project orders and retail orders**. The nature of KSA having two different order types arguably has a bigger impact on the production process of the roller blinds when compared with the impact on the production process which arises from the different roller blind variants.** Previously stated, project orders account for 16.666 of the 25.090 roller blinds which were produced in 2023, hence they are important to consider when upscaling production.

The production process of project orders is much more efficient than that of the retail orders. Since project orders are defined as any order with more than 25 blinds, they tend to be orders for new commercial or residential buildings, hence the blinds are usually from the same fabric and require the same metal profiles. The sawing and fabric cutting workstations are impacted positively from this. Moreover, in general, the process of producing the same blinds over and over when producing a project order makes them more efficient to produce.

In the first workstation, the sawing machine employee must walk back and forth to the inventory wall to grab the required metal profile which needs to be sawed. The standard size of the metal profile before it is sawed is six meters. For retail orders, the employee grabs the six meter profile from the inventory wall, then walks with it to the sawing machine. After sawing the required tube for the order, they take the six meter profile (it is less than six meters now) and return it to the inventory wall. With project orders, since most orders are for the same blind with the same profiles, the employee grabs the six meter profile and saws it to the required width. If, for example, the required width is two meters, they saw three parts out of the six meter tube and do not need to walk it back to the inventory wall since it is finished, saving time. So, the movement time is reduced with project orders in the first workstation.

In the fabric cutting workstation, if more than one blind can be cut from one fabric pull, then the fabric cutting machine could be much more efficient. For example, since the fabric cutting table is capable of cutting fabrics with up to 317cm of width, if the required width for a roller blind is 100cm, three roller blinds can be cut in one go (if the requested fabric is made in that size). This happens rarely with retail orders, since it is uncommon to have retail orders within the same time frame which demand the same fabric, from the 360 unique fabrics that KSA offers. However, for project orders, this happens often, since the orders are mostly from the same fabric. The cutting time for the fabrics of the roller blinds is drastically decreased from this. Moreover, with project orders, fabrics need to be changed less often. Although project orders mostly require jumbo rolls, which takes a much longer time to set-up, these rolls last much longer than the regular fabric rolls, and are changed much less often. Jumbo rolls can be up to 350m long. This allows the production planner to plan more orders after each other which do not require fabric changes, reducing the changeover times. Both of these benefits which come as a result of project orders - cutting more roller blinds from one fabric pull and less frequent fabric roll changes - cause complexities in the production planning. Efficiently optimizing the fabric cutting such that more roller blind fabrics can be cut from one fabric pull is currently not done to the full capacity, since optimally cutting fabrics in one go causes other complexities in production, such as a higher risk for the fabric to get damaged. Moreover, project orders and retail orders run concurrently at KSA, which also complicates the planning and makes it much more difficult to benefit from the benefits which come from project orders.

These benefits are addressed by the production planner. Since the production planner is aware of the efficiency associated with producing project orders, they plan more roller blinds to be produced during the project order production. This is done manually, not with the help of the ERP system. The ERP system’s production times are all based on retail orders. So, the production planner assumes that project orders are generally more efficient, although there is currently no figure at KSA that shows how much more efficient project orders are when compared with retail orders.

2.4 Chapter Summary

The second chapter examines the current production processes at KSA, by focusing on the steps taken to manufacture a roller blind. It does this by first explaining the characteristics and requirements of each roller blind variant. Following that, an overview of KSA's roller blind portfolio is examined, highlighting the variety and complexity of the products offered. The chapter also covers the standard operating procedures and workflow, illustrating the step-by-step production stages from raw material to finished product. Following the production process explanation, this chapter discusses how variety impacts the production processes at KSA. The variety is from the roller blind variants and the different order types. It is concluded that larger roller blinds take a longer time in production, and that project orders are much more efficient than retail orders with regard to production time and handling of materials.

3. Literature Review

This chapter reviews literature that can be used to solve the problem of meeting future demand for KSA. **Chapter 3.1** discusses Lean Manufacturing, a methodology used in production to decrease production "waste". Following this, **Chapter 3.2** goes through the many tools that Lean Manufacturing offers. Then, **Chapter 3.3** discusses utilizing process technology as a way to increase production output. Finally, **Chapter 3.4** summarizes the literature review.

3.1 Lean Manufacturing

Lean Manufacturing focuses on achieving a flow of materials to deliver the needs of customers, exactly when needed and at the lowest possible cost (Slack & Brandon-Jones, 2019, p. 515). It is closely related to another concept known as "just-in-time" (JIT). In the Lean Manufacturing philosophy, products are processed and passed to the next stage in a synchronized manner when requested, similar to JIT (Slack & Brandon-Jones, 2019, p. 520). The focus is on producing exactly the amount of products needed at the right time. Lean results in items flowing rapidly through processes, which results in efficiency of the overall system (Sagan, 2018). To achieve a flow of materials exactly when needed and at the lowest possible cost, wastes from the work processes must be removed, since they lead to inefficiencies in production. **Waste is defined as any non-value adding (NVA) process in production** (Sundar et al., 2014). NVA processes can then be described as either necessary NVA processes or unnecessary NVA processes. Necessary NVA processes are the processes that do not bring direct value to the customer but they ensure that the product or service that is delivered provides value to the customer. This could be for example, quality checks and testing the products. On the other hand, unnecessary NVA processes are considered pure waste, as they do not add value to customers (Krasteva, 2023).

When Lean Manufacturing was first introduced by Taiichi Ohno, the Chief Engineer at Toyota, waste was categorized into seven different types. Now, as the Lean Manufacturing philosophy made its way to the Western world, another category of waste was added, for a total of eight different categories of waste types (Skhmot, 2017):

1. **Transport**

   Wasted time, resources, and costs, which arise from unnecessarily moving products and materials.

2. **Inventory**

   Wastes from excess products and materials that are not processed.

3. **Motion**

   Wasted time and effort from unnecessary movement by people.

4. **Waiting**

   Wasted time from waiting for the next process step to occur.

5. **Overproduction**

   Waste from making more products than demanded by the customers.

6. **Over-processing**

   Wasted from more putting in more work or achieving higher quality than required.

7. **Defects**

   Waste from product failure to meet the customer's expectations.

8. **Skills**

Waste due to underutilization of talent, knowledge, and skills.

According to the Lean Manufacturing philosophy, these eight types of waste are caused by inefficient allocation of resources, which could be categorized into three Japanese terms: Muda, Mura, Muri. These three Japanese concepts are known as the 3M's of waste, and they provide guidelines for what to avoid, such that resources are allocation efficiently (Do, 2017):

Muda (wastefulness)

The concept of Muda is related to value-added (VA) work in a process that a customer is willing to pay for. There are two types of Muda, type 1 and type 2. Muda type 1 includes NVA activities in the process which are necessary for the customer, such as inspection of the product for a quality check, or safety testing. Although these activities do not add any value to the end product, they are needed to create it. Muda type 2 includes NVA activities in the process which are unnecessary for the end product, so they do not positively impact the customers. Muda type 2 should be eliminated.

Mura (unevenness)

Mura leads to Muda, since unevenness or irregularity in the production processes leads to waste. An example of Mura is if one workstation is producing products faster than another workstation in the process, then inventory is accumulated before the slower workstation, which creates unevenness in the production process. This leads to overproduction and excess inventory. The goal of a production system which utilizes the Lean Manufacturing philosophy is to level out the workload such that there is no unevenness.

Muri (overburden)

Muri can be caused by Mura. An example of Muri is if the production team is put under stress from unreasonable work that exceeds their capacity. It is related with the sixth waste category, "over-processing". Muri also applies to machines. If the machines are utilized more than 100% of their capabilities, then in the long-run, that could cause breakdowns of the machines. By standardizing work, and evenly distributing work processes, Muri can be avoided.

The concepts of Lean Manufacturing which were described above are validated through a case study. In Sameh and Mustafa's study (2021), the Lean Manufacturing philosophy and tools were applied to a food processing company to increase their energy efficiency. They started their research by categorizing waste and giving an example for each of these categories for the company they are performing their research for. Some of the included categories included waste from defects, transportation, motion, and waiting. They then introduced methods derived from Lean Manufacturing to tackle these problems. These methods are discussed in the next section of this chapter. The outcome of their study resulted in achieving their goal of reducing energy consumption, and they were also able to increase the productivity of the overall process, by increasing the performance of the machinery.

When identifying the core problem in section 1.2.3 of this report, the core problem of "Too many production inefficiencies" was selected. These inefficiencies were discovered through observation of the production processes' of KSA, and most of these inefficiencies could be labelled as waste, according to Sundar et al.'s (2014) definition. Since these inefficiencies are labelled as NVA processes, the Lean Manufacturing philosophy and tools will be used to reduce these production inefficiencies.

3.2 Lean Manufacturing Tools

There are several tools and methodologies which were derived from the Lean Manufacturing philosophy. These tools aid in reaching Kaizen (continuous improvement). Of these many tools, seven will be discussed which are useful for the research at KSA. While each tool contributes to the elimination of production inefficiencies, some excel in addressing specific types of waste. Therefore, the choice of tool is dependent upon the waste category and the context of the situation. The following section discusses these tools, and some sections include the application of these tools through analyzing case studies.

5S

The 5S methodology is a Japanese concept brought by the Toyota manager Taichi Ohno, and it is used to promote visibility (Sagan, 2018). It aims to achieve a cleaner and more organized workplace to keep things simple (Sameh & Mustafa, 2021). The 5S pillars according to Sagan (2018) and Slack & Brandon-Jones (2019) are as follows:

- Sort (seiri). Distinguish between what is not needed and what is needed. Keep what is needed and eliminate the rest.
- Straighten (seiton). Position things in the correct way to allow for easy retrieval.
- Shine (seiso). Keep the workplace clean and tidy.
- Standardize (seiketsu). Maintain cleanliness and order. The method which the other concepts are made habitual.
- Sustain (Shitsuke). Develop a commitment and pride in keeping to standards.

In the case study by Miroslav Sagan (2018) for the assembly line in an Electronic Manufacturing Facility, 5S was also applied. He improved the ergonomic and working environment of the employees by utilizing 5S. The new layout of the production facility was made based on 5S. The positioning of the workstations and materials were sorted in a way so the employees can easily access them when needed.

5S is currently being used in the assembly workstation, as there are shadow boards which hold the tools. However, it can be used in other workstations as well to reduce waste associated with transport, motion, and over-processing.

The 'Gemba Walk'

The 'Gemba walk' is a term often used in Lean Manufacturing which conveys the need of observation. If one really wants to understand something, they must go and observe it themselves (Slack et al., 2016, p. 508). Therefore, managers should regularly visit the production area to identify potential wastes.

The case study by Sameh and Mustafa (2021) which was done for the food processing company trying to increase their energy efficiency (discussed in previous sub-section) highlighted the importance of observation within their study. When identifying and categorizing waste at the company, they evaluated production line 22. Moreover, in another case study by Miroslav Sagan (2018) for the assembly line in an Electronic Manufacturing Facility, the method of observation is used when identifying waste within the layout that must be improved, and NVA processes. It is clear from these studies the importance of observation and being present at the place, not to just rely on data.

The production process for the roller blinds at KSA will be observed. Each workstation will be observed in detail; hence the Gemba Walk will be used throughout the whole study at KSA. Moreover, the Gemba Walk could be used when analyzing the possible solutions which are feasible for KSA at the fabric cutting workstation.

Takt time

Takt time can be used to set the pace of production. It is the rate at which the customers demand the product, dictating the rate of how production should be, to fill the customer demand (Liker, 2004).

$$Takt\ time = \frac{Available\ time\ for\ production}{Required\ unit\ of\ production}\ (Fansuri\ et\ al., 2018)$$

By using takt time, a production company can identify the required output per day. This number could be converted into the number of seconds between each product produced, which indicates the maximum allowed time per workstation to satisfy customer demand (Liker, 2004).

After identifying production inefficiencies at KSA and choosing the best ways to eliminate or reduce them, if the production output of the roller blinds does not reach the target, then more solutions will be made. These solutions will require calculating the takt time for the required output of 60.000 roller blinds per year, to know how many minutes each workstation can have to produce one roller blind.

SMED

Single-minute exchange of dies (SMED) is a lean manufacturing tool which is used to reduce the setup time of a machine by converting all internal activities into external activities. Internal activities are activities that require stopping the machines, whereas external activities are those that can be done while the machine is being used (Das et al., 2013). The goal of SMED is to complete as many steps as possible while the machine is running, saving time from change overs.

In a project done by Das et al. (2013) for an air-conditioning coil manufacturer, SMED and other Lean Manufacturing tools were used, which resulted in an increase in production output per shift from 121 coils to 214 coils, a 76% increase. This result was achieved partly from reducing the setup time of the expander machine, which was reduced from 60 to 20 minutes. The setup time of this machine was reduced to minimize the WIP and stream line the process. To start, Das et al. (2013) identified 18 different processes which are done by the machine that are categorized as internal activities, with a cumulative time of 57,97 minutes. By re-designing the machine and providing separate tools to different employees, they reduced the time to 19,15 minutes.

SMED can be utilized in this research in certain workstations. For example, the fabric cutting machine in workstation 2 can benefit from SMED to reduce the fabric changeover times. SMED is specifically useful for waste categorized as “waiting”.

Cellular manufacturing

Cellular manufacturing is a production system that integrates the processes of a production line into a single manufacturing cell. In cellular manufacturing, groups of parts are called families. These families are processed in clusters of machines called cells. The flow of the product through a cell is unidirectional, meaning that a product or part can skip a machine, however, it cannot backtrack (Kilpatrick, 1997). The goal for each cell is to have parts flowing based on the takt time. If there is inventory between the cells, it is viewed as an unbalance in the system.

The concept of cellular manufacturing could be especially useful for “transport” and “motion” wastes. For KSA, this tool can be used to reduce the production inefficiencies in the sawing workstation, since the parts often backtrack within this station.

Spaghetti diagram

A spaghetti diagram is a visual representation of the flow of an activity through a process. It is used to trace the path of the movement flow such that work flow improvements can be identified (Raikar et al., 2015). It is a useful methodology which is used as a lean manufacturing tool to reduce or eliminate waste categorized as motion or transport. The tool is named a spaghetti diagram because after drawing the full flow of an activity through a process, it often looks like spaghetti. However, the goal is to make the flow much simpler so that it does not look like a spaghetti anymore.

Coming up with a spaghetti diagram is simple. The first step is to draw the process layout, followed by drawing the path of the process from start to end within the process layout. Lines should be color coded to capture different material or employee movements. After creating the diagram, it should be used as inspiration for solutions. The longest paths should be eliminated by reducing their distances through machinery movement.

In a case study by Raikar et al. (2015), a spaghetti diagram was used to aid in identifying ways to reduce movement within an automotive components manufacturer. The goal of reducing movement was to increase one of the machines' availability to increase the OEE. After making the diagram, they identified the longest path one by one, and found a way to reduce it, until they were left with no possibilities to reduce anymore paths. Their solutions reduced waiting times by around 72%.

Within the context of this research, through observation, it has been noted that the first workstation (sawing) has excess movement. When observing the sawing employee, it was clear that the path they take is not efficient, as they spent more time moving around than sawing products. Hence, a spaghetti diagram is useful for the first workstation, to reduce the movement by the employee.

Pareto Principle

The Pareto Principle is named after the economist Vilfredo Pareto. It specifies that 80% of results come from 20% of actions, asserting unequal relationships between outputs and inputs. This rule is also known as the 80/20 rule. The Pareto Principle has also introduced Pareto Charts, which are used in Lean Manufacturing to analyze relationships between causes and effects of problems in processes (Toneva, 2024). By mapping out the problems and seeing their impacts, Pareto Charts help in shifting the focus on areas of improvement with the greatest impact.

In a case study done by Görener & Toker (2013) for a firm operating in forest products, the Pareto Principle was applied to improve the quality of the manufacturing process by reducing the defective products. Görener & Toker (2013) start by analyzing the workflow of the production process, and identifying the potential failures that occur within production. They were able to identify 11 failures. They then categorized them based on the 80/20 rules, and found that four of the 11 failures (36,4%) constituted to 74,4% of the total failures. They then used other methods to reduce these failures.

It is clear from this case study that using the Pareto Principle and creating a Pareto Chart can help with identifying the most problematic problems, which shifts the focus to them as they have the most positive impact when solved. The Pareto Principle could also be useful for optimizing the sawing workstation. The inventory wall which the sawing employee grabs the materials from could be organized in a way which makes it easier to find and get the profiles which account for 80% of the sales.

3.3 Process Technology

Technology has been around in operations for more than 300 years. It is a form of automation to replace human work activities (Slack & Brandon-Jones, 2019, p. 247). Slack and Brandon-Jones (2019) argue that in the last 20-years, the cost of industrial robots has decreased by half, whereas labor costs have doubled in developed economies during the same time period. They also argue that low-volume, high-variety operations can benefit from the use of VA technology. Moreover, they introduce three stages of process technology management, which are connected with questions. The stages are: understanding the potential of the technology, evaluating the impact on the performance of the operations, and developing an implementation strategy. The questions are (Slack & Brandon-Jones, 2019, p. 251):

1. What do operations managers need to know about a process technology?
2. How does the process technology affect the operation and the business?
3. How can operations managers introduce new process technology smoothly?

For the first question, operations managers need to know the possible risks that could arise from technology. They also need to be aware of the extensive possible process technologies, since there are many in the market, and how to choose the right one for their operations. For the second question, the process technology should fit with the volume-variety characteristics of the task it is intended to do. For high-variety and low-volume operations, the degree of automation should be general-purpose and small-scale, using flexible technology. For low-variety and high-volume operations, the degree of automation should be large-scale, using relatively inflexible technology. Moreover, deciding whether to automate a process can be seen as a cost to benefit question. Some of the things that operations managers should assess include what the technology can do, how fast it can do it, and how well it can do it in terms of quality. Moreover, they should assess whether the technology gives an acceptable financial return. For the final question, operations managers should implement Murphy's law when making an implementation plan. "If anything can go wrong, it will" (Slack & Brandon-Jones, 2019, p.270). They should plan long-term and analyze how the technology can integrate with the rest of their existing systems.

A case study by Sjøbakk et al (2014) shows how one company in Norway was able to use automation within one of their processes, the welding process. The case is for a Norwegian supplier to maritime industry. The company within the study follows an engineer-to-order manufacturing process as the customer decoupling point, since the items produced are highly customizable and have a high variation in terms of product types. Their aim from implementing new technology within the production process is to decrease their production costs. As a result of automating the welding process, their operations within this production step became four times faster, while consuming less materials. Although the aim of the company was to decrease the costs per product produced, as an outcome of the technology implementation, their cycle time reduced, and the available processing time increased. Moreover, Sjøbakk et al argue that if parts of the operations are already efficient, automation is not necessary, as the cost to benefit may not be significant enough.

For this research, the idea of automating some processes may be useful after identifying production inefficiencies. If the inefficiencies could be reduced by automating the processes', then automating certain parts of the processes will be considered.

3.4 Chapter Summary

Chapter three presents a comprehensive review of the existing literature on manufacturing processes, focusing on Lean Manufacturing. It starts by discussing the theory behind Lean Manufacturing, including the eight types of waste categories according to Lean. The chapter also defines value-adding and non-value adding processes. Then, the chapter explores tools derived from Lean, such as SMED, 5S, and spaghetti diagrams, which are methods used to minimize waste by reducing the non-value adding processes. The application of these tools in practice are examined through case studies and research. Finally, this chapter also identifies other methodologies of improving processes through technology. In conclusion, there are seven tools from the Lean Manufacturing toolset which are to be used within this research, and the idea of automating parts of production through technology is also to be used.

4. Problem Analysis

This chapter applies the theories which were discovered in the previous chapter to identify the production wastes, as defined by Lean Manufacturing. By doing so, the following research question will be answered: *"What are the biggest sources of production inefficiencies at KSA according to the findings from the literature, and what is the current production capacity at KSA?"* **Chapter 4.1** analyzes the production times, the current production capacity, and makes a distinction between VA and NVA processes, followed by **Chapter 4.2,** which uses these NVA times to identify and categorize the production wastes at KSA. The final section of this chapter, **Chapter 4.3,** summarizes the findings made with regard to the problem at KSA.

4.1 Production Times & Current Capacity

This section starts by discussing the production times per roller blind variant, followed by discussing the cycle time per workstation and per order type, which aids in calculating the current production capacity at KSA. The final sub-section of this section categorizes the production times per workstation into VA and NVA process times.

4.1.1 Production Times Per Roller Blind

As mentioned in the second chapter, the production times for each roller blind variant are different, and the production times for the same roller blind variant also differs, based on the fabric size of the order. Therefore, to determine the production times for each variant, the roller blinds are categorized into three different categories, based on their width size: 300-1.000mm, 1.000-2.000mm, and 2.000-3.000mm. The production times are then averaged for the sizes for each variant. The individual times for the Minimal Bracket range and the Bouroullec range are shown in two tables in appendix C.

After averaging the different size categories for each roller blind variant, there are still 29 different production times per workstation. Previously mentioned through a diagram in section 1.2.4, the demand for the different roller blind variants varies per roller blind model. It is clear that some of the variants' demand is less than 1% of the yearly demand, hence their production times should not hinder the processes' as much as other variants. For this reason, the sales data for the past three years is analyzed, and implemented into the production times.

Since KSA currently sell roller blinds from the Kvadrat Verosol portfolio, they must be accounted for within the sales percentages. The Kvadrat Verosol portfolio has many products which share characteristics with the Kvadrat Shade portfolio, therefore sales data from the Kvadrat Verosol portfolio are shifted to the Kvadrat Shade portfolio, assuming that the demand in 2025 will shift once the Kvadrat Verosol portfolio is phased out. Appendix D includes a table which shows the products from the Kvadrat Verosol collection, and highlights the replacement product from the newer Kvadrat Shade collection. Table 2 below shows the percentage of sales based on the product type, using the assumptions above and translating the past demand to the newer product range.

Table 2: KSA Profile Portfolio with Percentage of Demand. Adapted from QlikView [Computer software]

Bouroullec	Sales	Minimal Bracket	Sales
RCK-SA21	5,87%	RCKM-SA10	6,62%
RCK-SB21	0,58%	RCKM-SA11	3,15%
RCK-SA31	5,94%	RCKM-SB10	0,49%
RCK-SB31	0,59%	RCKM-SB11	0,27%
RCK-MA10	4,61%	RCKM-MA10	30,88%
RCK-MB10	2,06%	RCKM-MA11	15,95%
RCK-MI10	0,08%	RCKM-MA10-I	0,03%

RCK-MA21	6,60%	RCKM-MB10	3,17%
RCK-MB21	0,77%	RCKM-MB11	1,49%
RCK-MI21	0,06%	RCKM-MB10-I	0,01%
RCK-MA31	7,44%	RCKM-MI10	0,35%
RCK-MA31-I	0,04%	RCKM-MI11	0,19%
RCK-MB31	1,22%	RCKM-LA10	1,16%
RCK-MB31-I	0,10%	RCKM-LB10	0,24%
RCK-MI31	0,07%		

Moreover, for fabric welding, it is highlighted in the ERP system that in 2022 and 2023, there were an average of 1.118 roller blinds that were fabric welded. So, 4,45% of KSA's customers request their roller blinds to be fabric welded.

These sales percentages are then implemented with the production times. The weighted average times per model, in terms of their yearly demand percentage is calculated. Then, an average time per workstation can be found, shown in table 3.

Table 3: Average Time Per Roller Blind Production Step. Adapted from Microsoft AX [Computer software]

Production Step	Average Production Time Per Step (mm:ss)
Sawing	07:44
Fabric cutting	07:02
Pocket welding	03:02
Gathering materials	10:10
Assembly	06:30
Quality	05:47
Bubbling	02:52
Packaging	09:46

Although it may seem unrealistic to average the times required per workstation of all the roller blind variants into one time, it is clear that the production times for each roller blind model are close to each other. Models with the "-I" at the end require much more time, but their demand percentage is far too small to build a recommendation around them. That is why it is justifiable to take the production times by considering the yearly demand per variant. Moreover, the models that require more time to produce still follow the same steps in production. Currently KSA believe that their excess variation in products makes it more difficult to produce more roller blinds. Although that is true, they must realize that some of the roller blind variants offered which hinder the production process do not even account for 0,10% of the yearly demand, hence their effect is not as big as KSA believes. So, by taking the average weighted times, 30,88% of the times in table 3 are from the RCKM-MA10 model, which makes the times more realistic.

4.1.2 Cycle Times Per Workstations & Current Capacity

Now that the production times have been generalized for all the roller blind variants, the cycle times per workstation can be calculated. Cycle time is defined as the average time between items being processed (Slack & Brandon-Jones, 2019, p. 196). Since this section defines the cycle time per workstation, cycle time in this case is defined as the average time between items being processed per workstation. As aforementioned, project orders are more efficient, hence both cycle times will be analyzed separately, then combined with an average.

Retail Orders

The production times presented in the previous sub-section show the time required to produce a single roller blind, however it does not show the average time between items being processed within the workstations at KSA, the workstations' cycle times.

Currently, when a workstation has no work (because it has already processed all the work ahead of it), employees from those workstations go and help in other stations, hence the number of employees can differ. For the sawing station, there are usually two employees working, since there are two sawing machines. The fabric cutting has two employees, although there is one fabric cutting table. One employee operates the tables, while the other rolls the fabrics on to the tube. The pocket welding has no employees, and if there is an order that requires pocket welding, then only one employee works there, usually from the pleated blinds line. The material gathering has a range of two to three employees, same as the assembly workstation. The quality inspection has two employees, while the bubbling workstation has one. Finally, the packaging workstation has two employees. Table 4 below shows the average cycle time per workstation based on the minimum number of employees, totaling 12 employees for the roller blind production. Coming up with the average cycle time per workstation consists of dividing the average production times for the roller blinds with the number of operational machines/employees at the station.

Table 4: Cycle Time Per Workstation Retail Orders

Production Step	Number of Machines (employees)	Average Cycle Time Per Workstation Retail Orders (mm:ss)
Sawing	2 (2)	03:52
Fabric cutting	1 (1-2)	07:02
Pocket welding	1 (0-1)	03:02
Gathering materials	1 (2-3)	05:05
Assembly	6 (2-3)	03:15
Quality	2 (2)	02:53
Bubbling	2 (1)	02:52
Packaging	3 (2)	04:53

Project Orders

Coming up with the cycle times per workstation for project orders required timing project orders in the production process, since there is no data available to identify the efficiency of project orders. **This was done based on <u>three</u> different observations.** Section 2.3.2 highlighted ways in which project orders are more efficient than retail orders. This section will discuss the actual efficiencies in numbers.

There are many steps at each workstation for producing the roller blinds, and some of these steps only need to be done once when producing project orders, hence, they save a lot of time in production. For example, in the sawing station, the employee only needs to grab the materials from the inventory wall once to saw three different parts for three different blinds, compared to a retail order, where the employee walks for the same amount of time but only saws one piece for one blind. Appendix E includes eight tables which show all of the steps taken per workstation, and highlights the ones which are more efficient for project orders.

Table 5 below shows the efficiency percentage in the middle column based on observation and calculations. To calculate the efficiency percentage, the time taken to produce one roller blind was compared to the time taken to produce multiple roller blinds, depending on the time the observation happened.

Table 5: Average Cycle Time Per Blind Project Orders

Production Step	Efficiency Percentage	Cycle Time Per Workstation Project Orders (mm:ss)
Sawing	57,8%	01:38
Fabric cutting	61,7%	02:42
Pocket welding	0%	03:02
Gathering materials	50%	02:32
Assembly	13,6%	02:49
Quality	16,7%	02:24
Bubbling	16,5%	02:24
Packaging	63,9%	01:46

For the fabric cutting table, the project orders observed all had different efficiencies, since the number of roller blinds cut from one fabric pull is dependent on the size requested for the roller blind. For this reason, 3.120 roller blind orders were analyzed for 2024 (the only available data was for 2024). These 3.120 roller blinds used 943 fabric markers (fabric pulls). That means that on average, 3,31 roller blinds were cut per fabric pull in 2024. This time was used to calculate the efficiency percentage of the fabric cutting workstation. Only the times that are impacted by project orders were divided by 3,31, so for example, rolling the roller blinds to the tubes is not divided by 3,31, since it does not become more efficient with project orders. Moreover, the pocket welding efficiency is 0%, since the constraint is the machine capacity, and the efficiency for packaging is much higher than the rest, because multiple roller blinds are packaged together in one box, following the same steps as packaging one roller blind.

Combined Averaged Cycle Times

The solutions which will be presented in the next chapter will include the weighted average times' of the project orders and retail orders, with their demand percentages (67% and 33%). Knowing the difference in times is vital, since retail orders take much more time to produce, a solution must satisfy both order types. For this reason, these times are averaged here. Table 6 shows these times, based on all the assumptions made from the previous sections.

Table 6: Average Cycle Time Per Blind Project & Retail Orders Weighted Average

Production Step	Averaged Cycle Times Project and Retail Orders Per Workstation (mm:ss)	Current Roller Blind Capacity Per Year
Sawing	02:22	48.676
Fabric cutting	04:08	27.870
Fabric welding	03:02	37.978
Gathering materials	03:22	34.217
Assembly	2:58	38.831
Quality	2:34	45.000
Bubbling	2:33	45.176
Packaging	2:47	41.389

Required Averaged Cycle Times

Increasing the production output to 60.000 roller blinds would require a roller blind to be produced every minute and 56 seconds, according to the takt time formula:

$$Takt\ time = \frac{Available\ time\ for\ production}{Required\ unit\ of\ production}\ (Fansuri\ et\ al., 2018)$$

$$Available\ time\ for\ production = (7{,}5\ hours * 60\ minutes) * 256\ production\ days$$

$$Takt\ time = \frac{115.200}{60.000} = 1{,}92\ minutes = 01{:}56$$

So, the overall goal is to reduce the workstations' cycle time to 01:56.

Current Production Capacity

Based on the cycle times from table 6, the production capacity for each workstation is also calculated, by dividing the available time for production with the station which has the highest average cycle time, the fabric cutting. **This results in 27.870 roller blinds per year, which is the current production capacity at KSA.**

It is clear from this table that the fabric cutting is the current production bottleneck at KSA, followed by the material gathering and the pocket welding. However, the pocket welding is only required for 4,45% of the products, so from the 60.000 future demand of roller blinds, only 2.670 roller blinds will need to be pocket welded.

4.1.3 Categorization of Production Times

Based on the times from the previous sub-sections, the production times will be categorized into NVA and VA processes. For KSA, any VA process includes processes which add value to their customers. That is, processes that add value to the roller blinds. So, NVA process are those that may be necessary, but do not directly contribute to satisfying the customer, as defined in chapter 3.

Since the production times vary per order, the NVA and VA processes are categorized based on percentages. Figure 12 below presents a visual diagram that shows the time spent on VA vs NVA processes within the production of the roller blinds at KSA, per workstation.

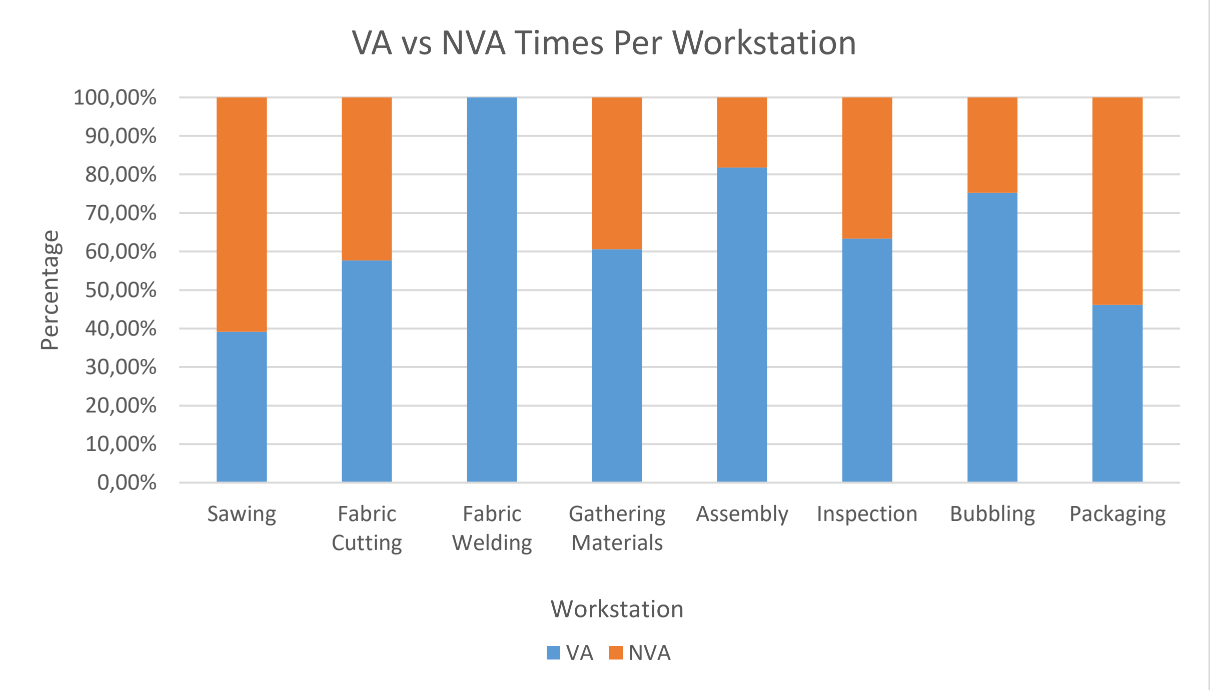


Figure 12: VA vs NVA Processes Visualized

The NVA processes come from different sources in each workstation. These are shown in figure 13 in detail.

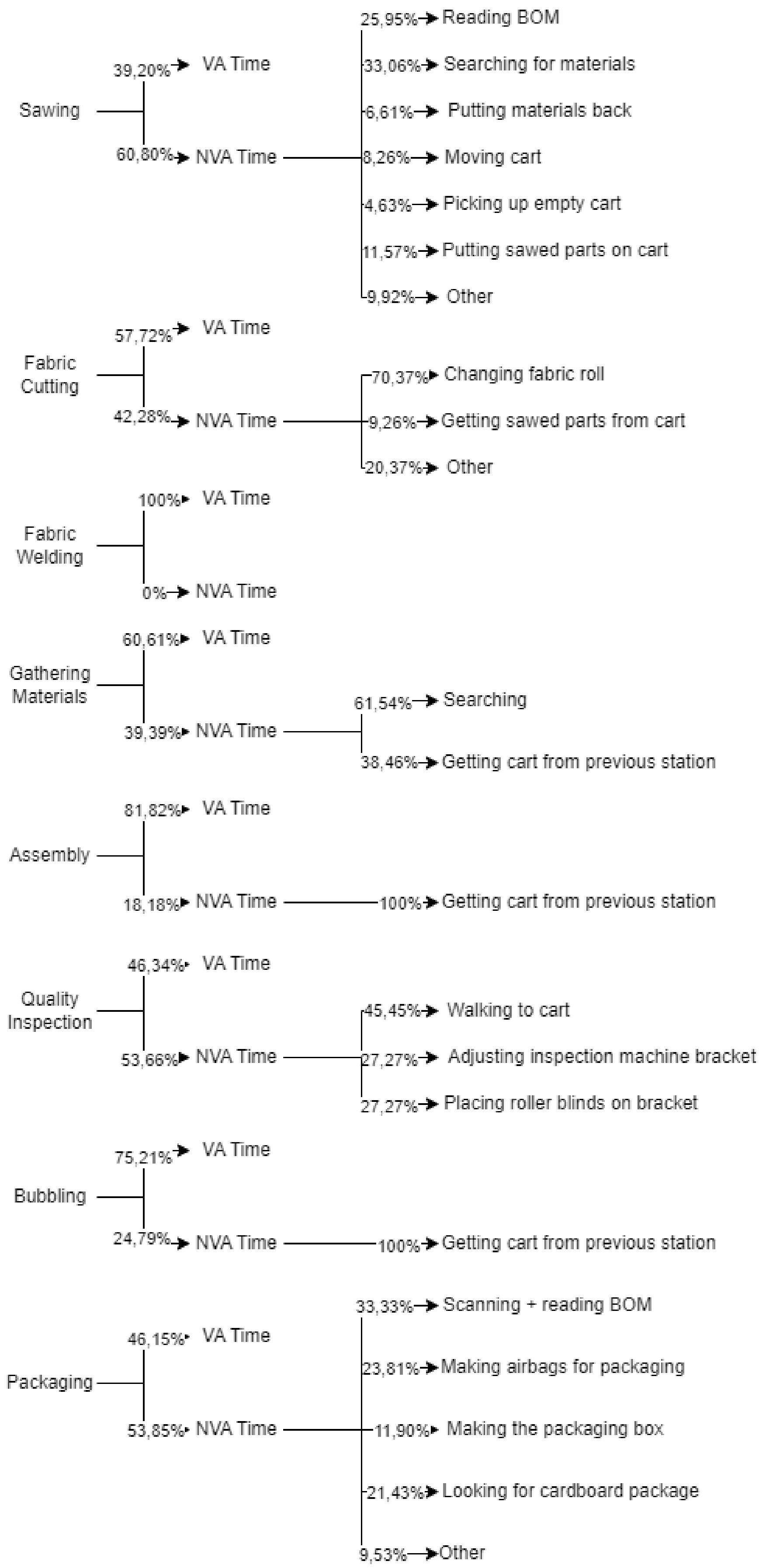


Figure 13: NVA Processes Detailed

At the sawing workstation, the first NVA process was from excess reading of the BOM. The sawing employee was constantly reading the BOM to see which material they needed to grab from the inventory wall. The second NVA process was searching for the materials. Each time a profile needed to be sawn, the employee would walk to the inventory wall, get the materials, and come back to the sawing machine. Then, they would once again grab new material for another profile that needs to be sawn, adding a lot of time to the sawing process. The other three NVA processes arise from the cart system.

The fabric cutting workstation's NVA processes are mainly from the changing of the fabric roll. The 'other' NVA times consisted mainly of throwing away extra fabric and moving the cut fabric to the rolling table, for the other employee to roll the fabric onto the tube.

The fabric welding station had no NVA processes, since it is located directly next to the fabric cutting workstation, so the cart is not moved. The material gathering station's NVA process was mainly time spent searching for materials. The items are categorized in shelves, and they are easy to reach, however, it still takes time to move around the shelves and get the necessary items.

In the assembly workstation, again, the NVA process was getting the cart from the previous station. Although the employee spent some time reading the BOM, it was considered a VA process since it is their 'instruction manual' for making the roller blinds.

The quality inspection's most time consuming NVA process is walking to the cart from the previous station (the assembly), and bringing it to the quality station. The two other NVA processes are both related to adjusting the machine for the roller blinds. The bubbling station had 100% of the NVA process time being from the cart as well.

The final station, the packaging, had multiple NVA processes. 33,33% of the NVA time was spent on scanning the BOM. This is done to update the ERP system of the order, marking it as complete. Scanning the BOM included both VA and NVA times, since it is also the step in which the packager prints the stickers for shipping. The second most time consuming NVA process was filling up the airbags for packaging. They are filled by the packaging employee in a big box, and used just before closing the package. The third most time consuming NVA was the employee walking to the area of the cardboard boxes and getting the right sized cardboard piece to make into a box. Some other NVA processes were creating the box from the cardboard, and grabbing the roller blinds from the carts. The packaging employee does not need to bring the roller blinds from the previous station, since the packaging and bubbling stations are very close to each other.

4.2 The Production Wastes

Chapter 3 introduced the concept of Lean Manufacturing, and section 4.1.3 categorized the production times based on VA and NVA processes' times. Using the NVA processes' times aids in identifying the production inefficiencies in the production process of roller blinds at KSA. These production inefficiencies can be called "wastes", as defined in the Lean Manufacturing philosophy. Many production wastes were identified at KSA, however, many of them have commonalities, so they are summarized into five different wastes. The main production wastes identified at KSA are:

1. **Material handling**

   The key issue regarding material handling is that employees must take time to search for materials, carry them, and walk with them to their workstations, causing delays and disruptions in the production process, since it takes away valuable time from the production process, and increases the cycle time per workstation. This is seen specifically at the first workstation (sawing), the second workstation (fabric cutting), and the last workstation (packaging). At the sawing station, the employee is constantly looking for materials which need to be sawn. The employee walks to the inventory wall shown in figure 14 below, and searches for the required aluminum profiles for the order. For the fabric cutting, the employee needs to handle the fabric rolls before each new order, which also takes away valuable time from the cutting workstation. Finally, the packaging workstation employee also spends valuable time searching for the cardboard required to make a packaging box for the order.

Figure 14: Inventory Wall KSA

For the sawing workstation, there are many profiles placed in the inventory wall which are not used often. For this reason, a Pareto analysis is made as figure 15 below, which can be useful when coming up with solutions.

There are six different categories of profiles. One of them are the profiles which are not in the collection anymore, another is the custom made products, another is the from the Verosol collection. There is also a category of items being phased out. Next year, the Verosol collection will become part of the phased out category. The final and most important category of profiles is the Kvadrat Shade profiles, which will be the one used for the Pareto analysis, since it has the highest usage value of all categories, and is the one concerned with the 2025 product portfolio of KSA.

Within the Kvadrat Shade profiles collection, there are 71 different profiles. These profiles include the tubes, cassettes, bottom profiles, and more. Of these 71 profiles, three of them are class A items, which cover a sales percentage of 83,9% (based on the averaged data from 2022 and 2023). Then, two more profiles are in class B, which account for 91,44% of the total sales when combined with the class A profiles. The Pareto diagram is shown below. It is clear that many of the profiles are not being used at all currently.

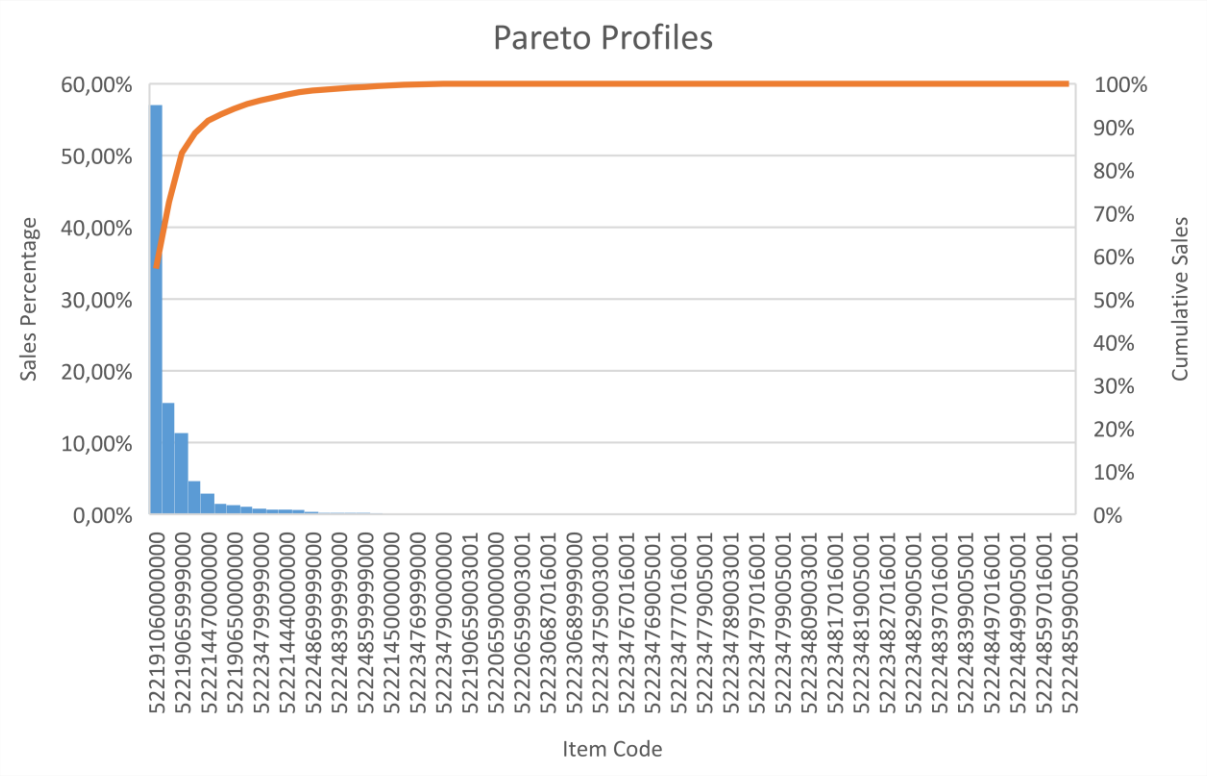
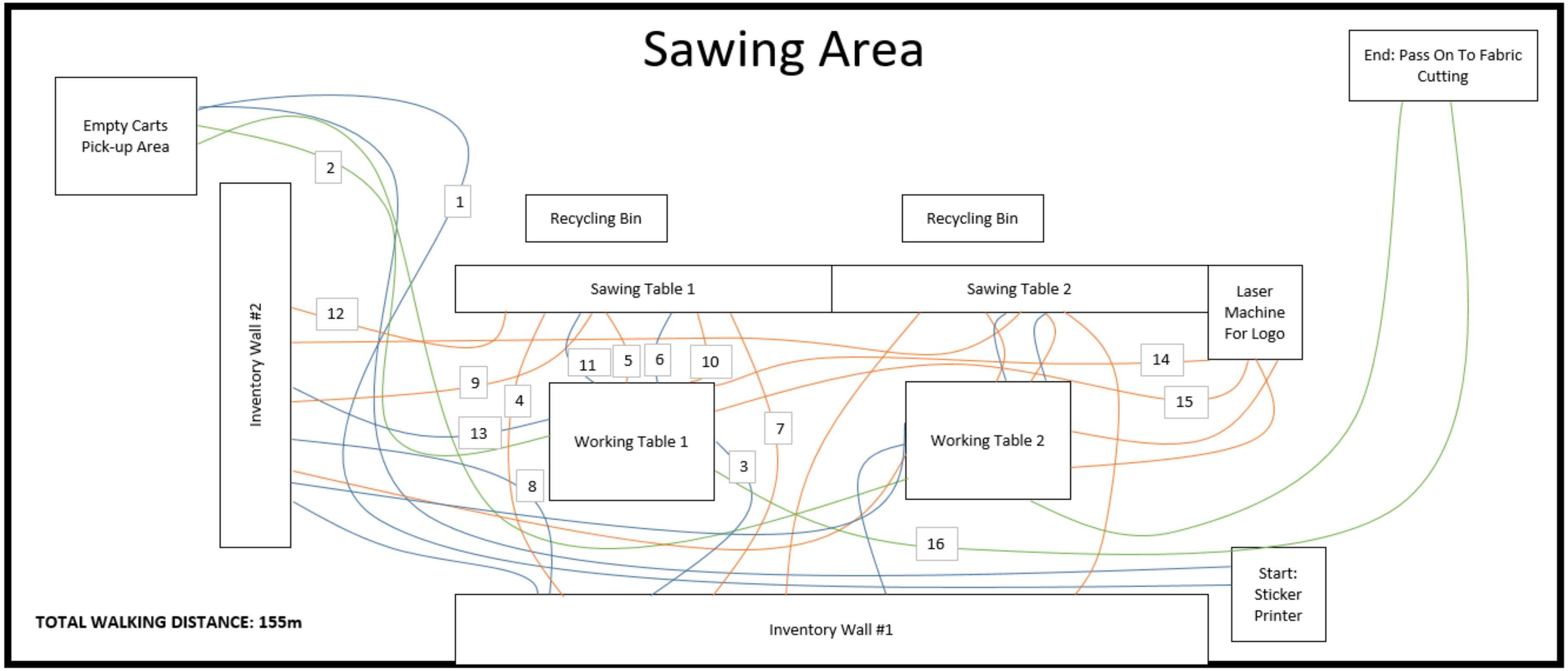


Figure 15: Pareto Profiles

2. **Employee walking paths**

The employee walking paths at KSA are not optimal, especially at the first and last workstations. A spaghetti diagram is made for both stations below, as figures 16 and 17. It is obvious that the walking paths at the sawing area are not optimal, as the employees walk back and forth often, and they have very long walking paths, for example, from the starting area where they print the stickers, they must walk all the way to the empty carts section to bring a new cart. The key issue with these suboptimal walking paths is that it reduces the productive time in production, and it increases fatigue of employees due to excessive and unnecessary movement. Similarly for the packaging area, the walk to the cardboard storage area accounts for over 20% of the NVA time within the process.



Legend

- Walking empty handed
- Walking with cart
- Walking with parts

Step 1: Start to empty cart
Step 2: Empty cart to working table 1
Step 3: Table 1 to first inventory wall
Step 4: Inventory wall 1 to sawing 1
Step 5: Move sawed piece to cart at table 1
Step 6: Go back to sawing table 1
Step 7: Bring back material to inventory wall 1
Step 8: Walk from inventory wall 1 to 2
Step 9: Second inventory wall to sawing table 1
Step 10: Move sawed piece to cart at working table 1
Step 11: Go back to the sawing table
Step 12: Bring back material to inventory wall 2
Step 13: Walk back to working table for bottom profile
Step 14: Walk to laser machine to engrave logo
Step 15: Walk back to cart at working table 1
Step 16: Walk with finished cart fo fabric cutting

Figure 16: Sawing Spaghetti Diagram

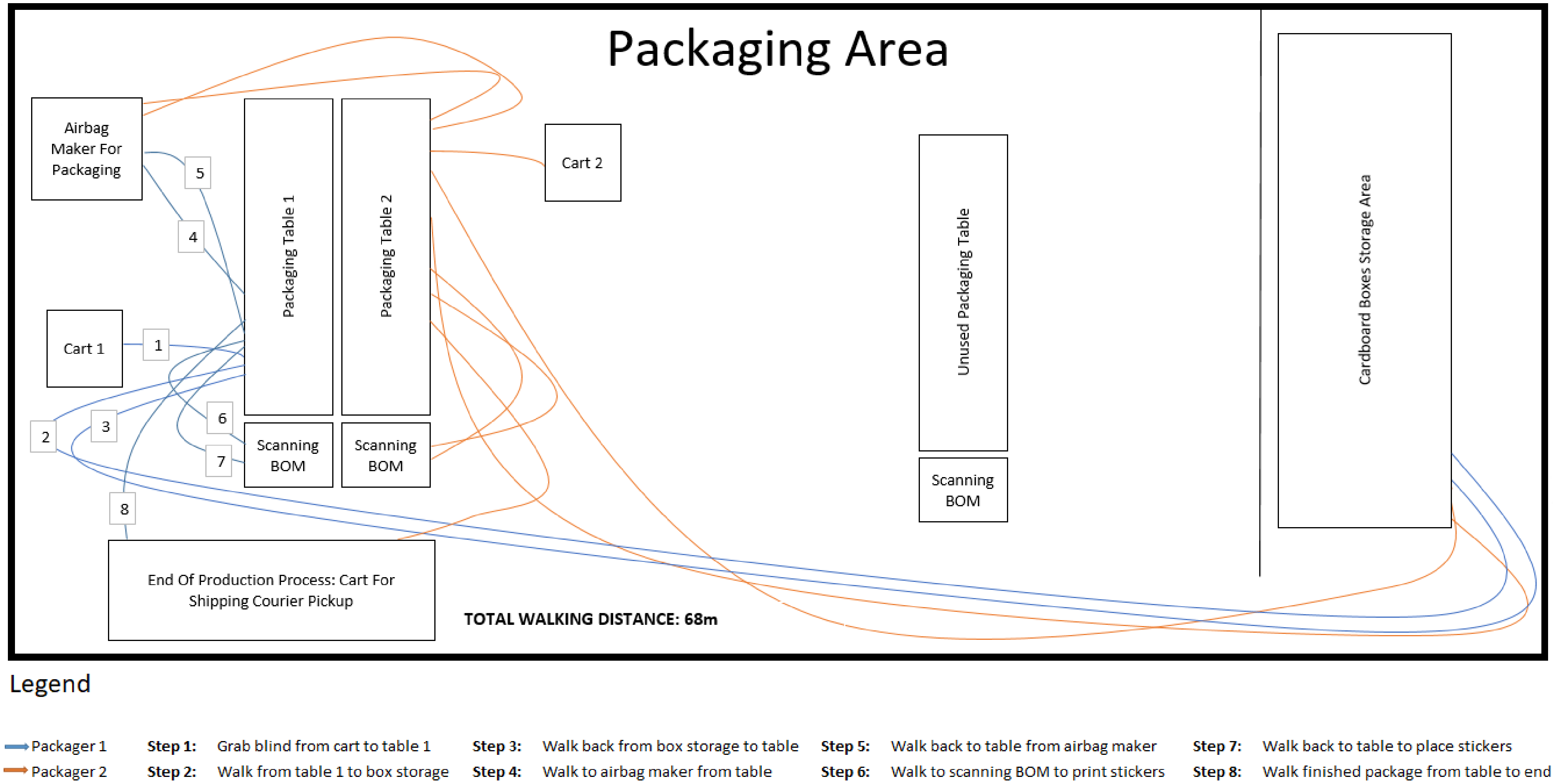


Figure 17: Packaging Spaghetti Diagram

3. **Startup inefficiencies**

   The third problem of startup inefficiencies causes a key issue of extended setup times, leading to delays in production and reduced overall production efficiency. This problem is closely related to the problem of material handling, as being well prepared for a production run can also reduce the time spent on searching for materials. One issue that was noticed in both the first and last workstations was the constant reading of the BOM. The employees would stop their work to read the BOM in detail, because the exact steps of production are not laid out to them. The sawing employee looks at the code of the part they need to find, which takes a while, since it requires a lot of time to find the exact color and code of the needed material. With good preparation, the required materials for the production orders of the day can be ready for the employees to simply pick them up and start sawing. Similarly, in the packaging area, the employee must make the airbags to protect the roller blinds within the packaging box, and they also need to search for a cardboard box to package the roller blinds in. These items should already be prepared, since making the airbags alone accounted for almost 24% of the NVA time.

4. **The cart system**

   As mentioned before, the cart system at KSA is used to move the unfinished and finished roller blinds from one workstation to the next, starting at the sawing workstation, and ending at the packaging station. The key issue associated with using the cart system is that employees must stop doing VA processes at their workstations in order to move the cart to the next station or pick up their carts from the previous workstation. Once again, this wastes valuable time and causes interruptions in production. The problem is that previously, there was a conveyer belt at KSA, which was sold for metal scrap parts later. That is because it would overflow before the fabric cutting station and the sawing would need to stop and wait for the conveyer belt to be empty again. Using a conveyer system is only possible if there is somewhat of a balanced flow between the workstations, which currently, there is not. Moreover, the employees at KSA are very accustomed to the cart system and would not like to change it. The parts also need to be tracked between the workstations since each part is unique for a certain roller blind order, so it is difficult to get rid of the cart system at the moment, but it should be enhanced somehow in order to reduce the NVA time which is caused by it.

5. **Fabric changeover time**

   The key issue which arises from the long changeover times of the fabrics at KSA is the significant downtime of the fabric cutting table and the lower production output of the overall process. Over 70% of the NVA processes at the second workstation is due to the fabric roll being changed. The employee spends time removing the previous fabric roll, identifying the new roll to pick up, driving the fabric pick-up car to pick the fabric up, and installing the new fabric roll. Since the current bottleneck in production is the fabric cutting table, reducing the time spent at this workstation will increase the production output of KSA. There must always be some sort of time spent on changing the roll, but this time can be reduced.

These five identified and generalized production wastes at KSA need to be reduced or removed in the next chapter through solutions and recommendations. To choose the best fitting method of solving these issues, the right Lean Manufacturing tools should be used. Table 7 below summarizes the five identified production wastes in terms of the type of Lean Manufacturing waste associated with them, the location of the waste at KSA, and the Lean Manufacturing tools which fit best with solving the associated problems. Additionally, problems 4 and 5 could use the literature related to process technology.

Table 7: Summary of Production Waste at KSA

Production Inefficiency	Type of Lean Manufacturing Waste	Location of Waste (Workstation)	Lean Manufacturing Tool(s)
1	Transportation, Motion	1, 2, 4, 8	Spaghetti diagram, 5S
2	Transportation, Motion	1, 8	Spaghetti diagram, cellular manufacturing, 5S
3	Waiting	1, 2, 6, 8	SMED
4	Waiting, Motion, Transportation	1, 4, 5, 6, 7	The Gemba Walk, SMED
5	Waiting	2	SMED

4.3 Chapter Summary

The fourth chapter of this research focuses on a detailed analysis of the current production processes at KSA. The initial step involved evaluating production times per roller blind and the cycle times for each workstation, revealing a significant gap between the estimated and actual production capacity. KSA estimates an annual production capacity of 30.000 roller blinds, but the actual calculated capacity is 27.870. Then, through observation, the production process is timed in order to categorize the production times into VA and NVA processes. The results of the observation show that a significant portion of the production time is consumed by NVA activities, which do not directly contribute to the final product. This categorization helps pinpoint areas with the greatest potential for improvements. By highlighting the NVA process within each workstation, five inefficiencies in production were identified, which include: excessive material handling, suboptimal employee walking paths, startup inefficiencies, problems with the cart system, and slow fabric changeover times. By identifying the main production inefficiencies at KSA, the solutions can be made based on these inefficiencies.

5. Solution Approach & Analysis

The fifth chapter presents and analyzes seven potential solutions to the five identified wastes in production from the previous chapter. In doing so, the following two research questions are answered:

1. *"What are the best ways to deal with the identified production inefficiencies?"*
2. *"What production benefits can be derived from addressing the issues identified in the previous question, and what additional improvements are necessary to reach the target production output of 60k roller blinds per year?"*

Chapter 5.1 introduces and analyzes the first two potential solutions of redesigning the sawing and packaging workstation layouts. **Chapter 5.2** then identifies two solutions for the whole production facilities of KSA and analyzes them. Then, **Chapter 5.3** identifies and analyzes three more possible solutions for the issue of the fabric changeover times. Following that, **Chapter 5.4** combines the solutions together and identifies the solutions which can make KSA reach the target output of 60k roller blinds per year. Finally, **Chapter 5.5** summarizes the chapter.

For the solution analysis, the solutions will be tested based on the yearly production capacity and the costs of the solution. **A test run will be conducted for the solutions that are feasible to test and within resource constraints. Solutions that are too costly or impractical to test within the given timeframe will be evaluated theoretically, using calculations to estimate their expected benefits.**

5.1 Specific Area Redesigns

The first solution presented in this section is for the sawing workstation, and the second solution is for the packaging area, which had high amounts of waste due to motion and transportation.

5.1.1 Solution 1: Sawing Workstation Layout Redesign

Problems addressed: Material handling, employee walking paths, startup inefficiencies

Description: The current layout of the sawing area is presented in figure 18. This is the same figure that was presented as a spaghetti diagram in the previous chapter, but without the walking paths.

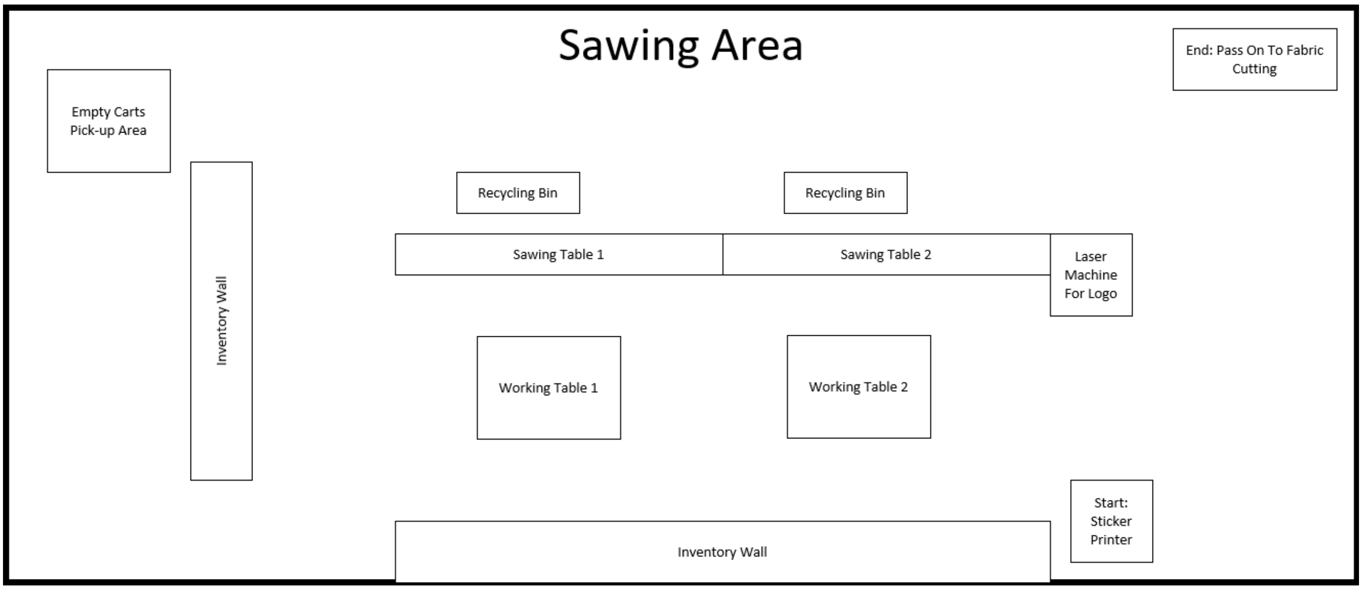


Figure 18: Current Layout Sawing Area

There are many problems with this current layout which lead to excess movement by the employees. The new proposed layout for the sawing area is shown as figure 19.

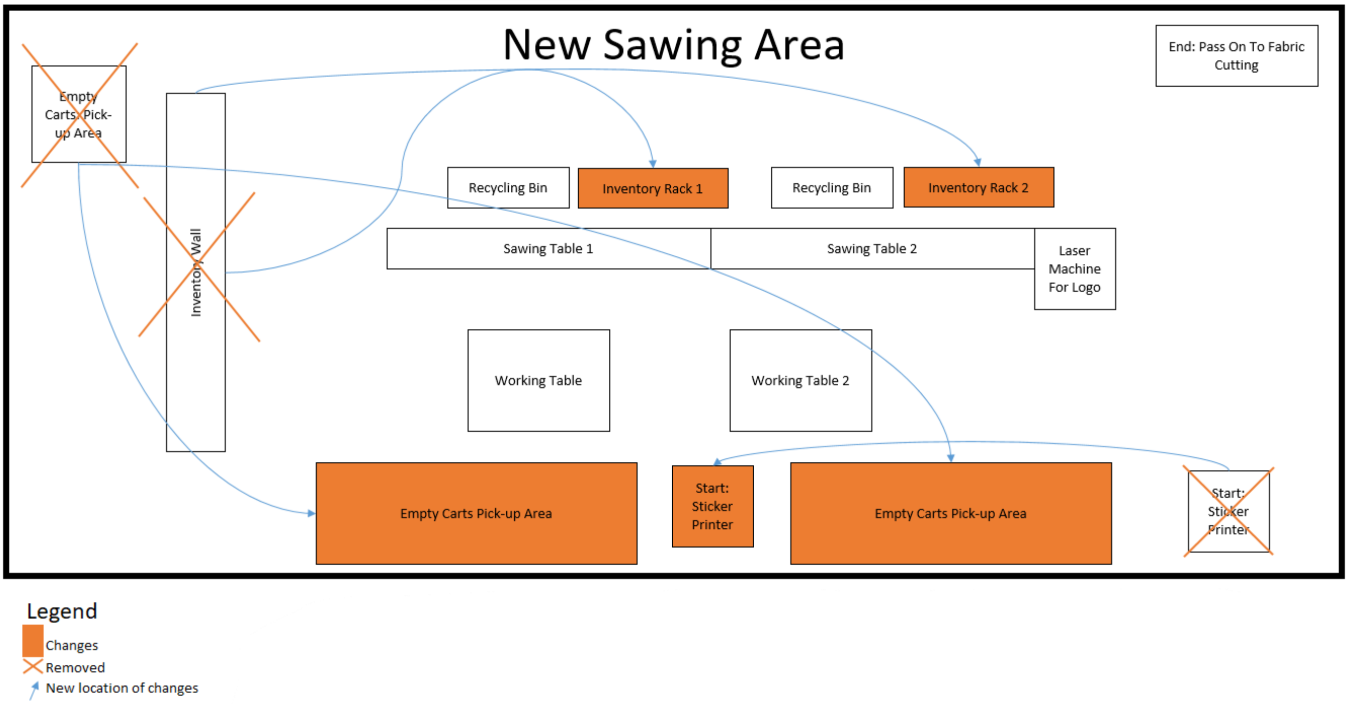


Figure 19: New Proposed Layout Sawing Area

The new layout totally removes the inventory walls, and replaces them with two new inventory racks, which are racks that are placed close to the sawing tables, with the required profiles which will be sawed on the given production day. The inventory racks are accessible from the sawing table without movement from the employee. Adding the inventory rack will require moving the inventory wall into the warehouse section (which has the space for this), or consequently, it can also be placed on the left side of the new layout, since there is plenty of space there now. This inventory rack will hold the class A and class B profiles (based on the Pareto analysis in chapter four). This reduces the time spent by the employees searching for the required materials, which reduces the internal activities, utilizing the concept behind SMED.

The next change in the layout is the movement of the empty carts pick up area and the sticker printer. The empty carts are now placed where the old inventory wall is, and the sticker printer is in between the empty carts area, so it can serve both employees equally.

The final change is with regards to the moving path. This is explained in the upcoming expected benefits section.

Costs: Moving the items around

= **224 euros**

If calculated hourly, on average, each employee makes 16 euros an hour. Most time will be spent on the inventory walls. It will take around 10 hours total to carry all of the materials and racks to the warehouse. It will take around two hours to set-up the new racks, and another hour to set-up the required profiles for the first test production run. Moving the sticker printer and empty carts should both take a total of one hour. Therefore, the total hours are around 14 hours, with each costing 16 euros.

Expected Benefits:

1. Shorter walk from start to empty carts
2. Shorter walk from empty cart to working table
3. No walking to inventory wall
4. Less time for engraving KSA logo

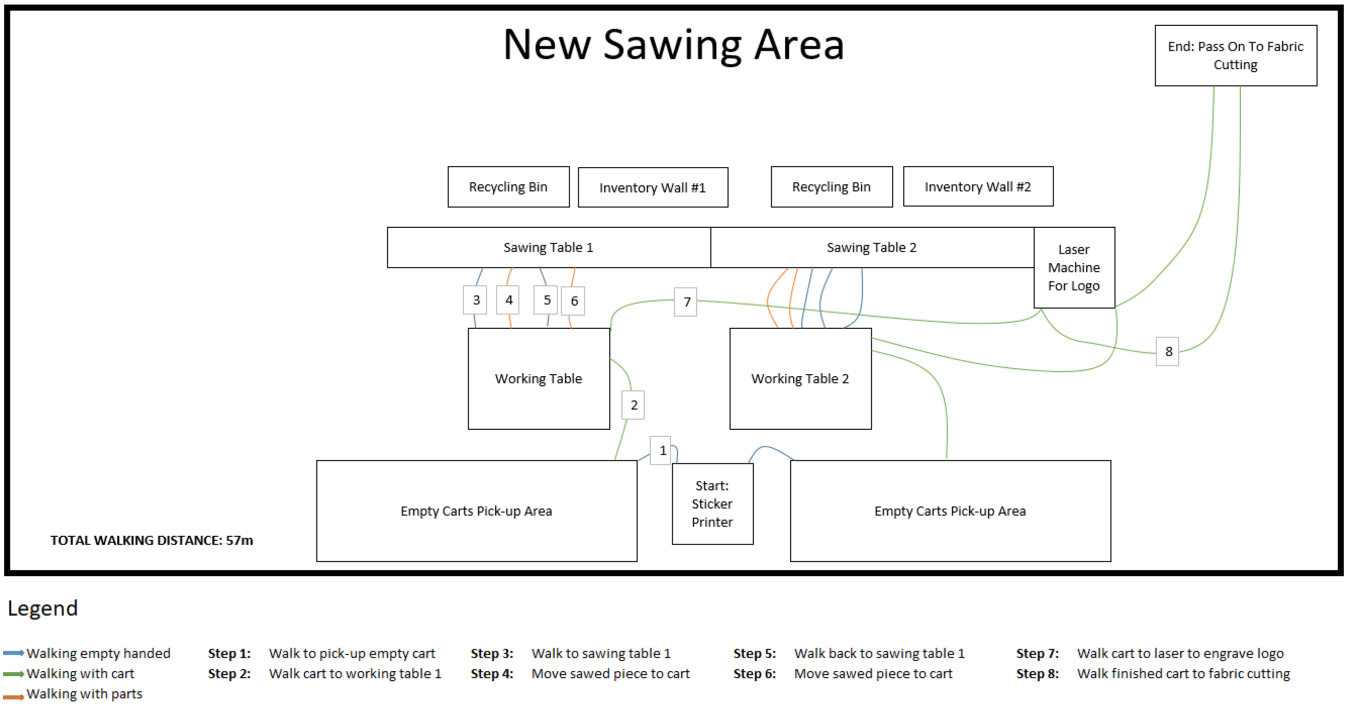


Figure 20: Improved Sawing Spaghetti Diagram

The new layout for the sawing workstation reduces the total walking distance, as can be seen in figure 20. The results of the layout redesign with regard to the walking distances and number of steps taken is shown in table 8. The new walking distance for the sawing employee sees a 63,23% reduction.

Table 8: Sawing Walking Distance & Steps Current vs New (Solution 1)

Current Walking Distance	New Walking Distance	Current Number of Tasks	New Number of Tasks
155 meters	57 meters	16	8

Additionally, the walking path is changed, by using the theory behind cellular manufacturing. Currently, employees walk to the laser machine to engrave the logo, and back to the working table. However, with this new layout, an instruction is given to the workers to make a stop at the laser machine with the cart, engrave the logo, then immediately push the cart to the fabric cutting station.

This new layout reduces the time spent searching for materials, the time spent picking up new carts, and the time spent putting materials back. **Searching for materials becomes 0% of the NVA process, from the previous 33,06% (since there is no need to search for them anymore). The time spent picking up new carts drops from 4,63% of the NVA process to 2,80%. Finally, the time spent putting materials back becomes 2,80% of the NVA processes, which is currently 6,61% of the NVA processes. The total VA time percentage goes up from 39,20% to 52,21%.**

With these improved times, table 9 shows the impact on the production output.

Table 9: New Production Output Solution 1 Sawing Workstation

Current Sawing Workstation Cycle Time (mm:ss)	Future Sawing Workstation Cycle Time (mm:ss)	Current Yearly Production Output Sawing Workstation	Future Yearly Production Output Sawing Workstation
02:22	01:47	48.676	64.598

Although this solution increases the sawing output to 64.598 roller blinds per year, it will not increase KSA's overall output, since the fabric cutting table is still the bottleneck in this case. Hence, this solution needs to be combined with other solutions.

5.1.2 Solution 2: Packaging Workstation Layout Redesign

Problems addressed: Material handling, employee walking paths, startup inefficiencies

Description: The current layout of the packaging workstation is presented as figure 21.

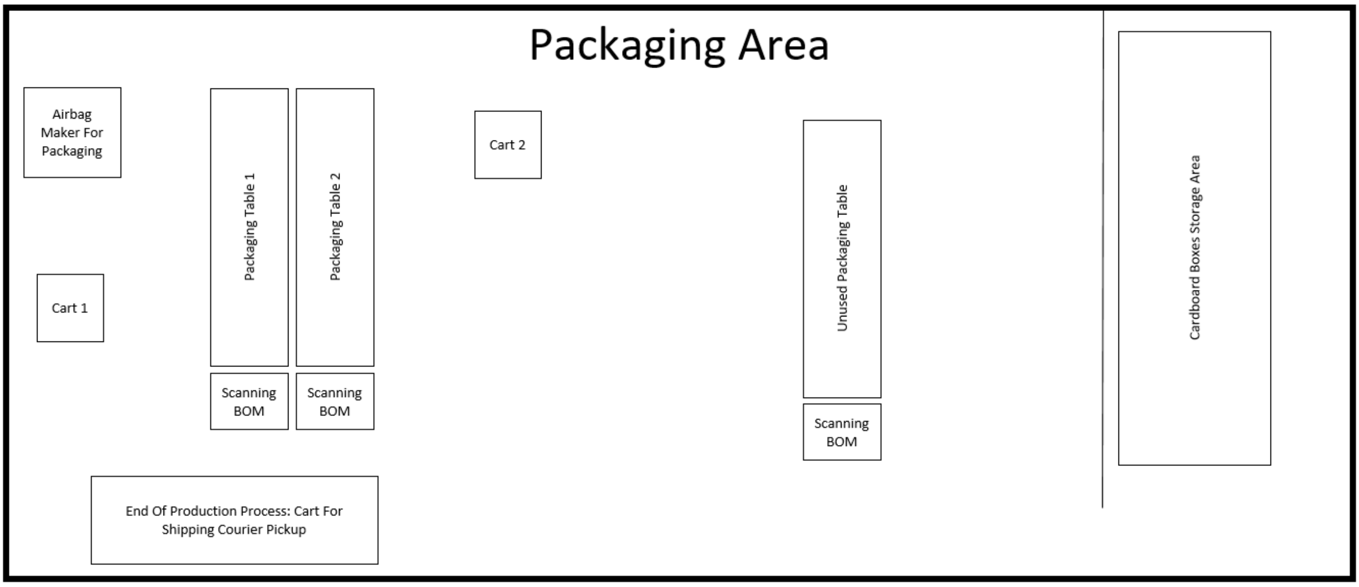


Figure 21: Current Layout Packaging Area

In the current layout, there is a third unused packaging table. This will stay the same with the new layout, since there are currently only two employees which can work in the packaging area. The main problem with this current layout is the walking path and the lack of preparation/availability for both the airbag maker and the boxes. The new proposed layout is presented below as figure 22.

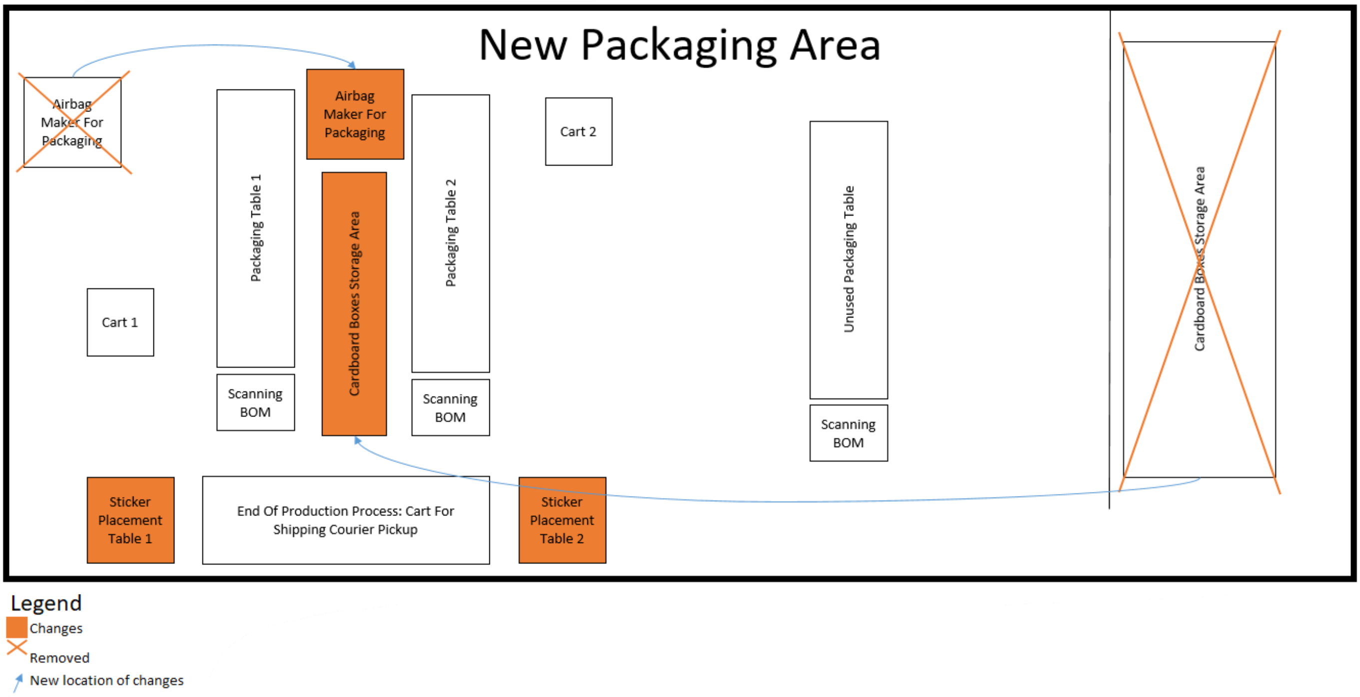


Figure 22: New Proposed Layout Packaging Area

The first change in the new layout is the introduction of a rack for storing the cardboard boxes, in between the two packaging tables. Similar to the sawing area, this eliminates the need to walk all the way to the original storage area. Once again, the boxes will need to be pre-made for production. <u>Pre-making the boxes takes more time, but it could be done by either the warehouse employees, or by an employee from another workstation which is not busy or has a shorter cycle time. Else, they can be purchased pre-made for an additional cost.</u> The final change for the packaging area is the introduction of two new tables next to the end product cart. These tables allow for a better flow for the employee once they print the shipping stickers, utilizing the theory behind cellular manufacturing.

Costs: Moving the items around + Two new tables

= 96 + 400

= **496 euros**

Moving the items around should take a total of six hours. Removing the current cardboard storage and setting up the new racks should take around three hours. Installing the new tables and moving the other items around should take two hours. The final hour will be spent on setting up the cardboard boxes for the first production run. Each new table costs around 200 euros.

Expected Benefits:

1. No more walking to cardboard boxes storage area
2. Shorter walk to airbag maker
3. Walking times reduces when printing stickers due to new tables

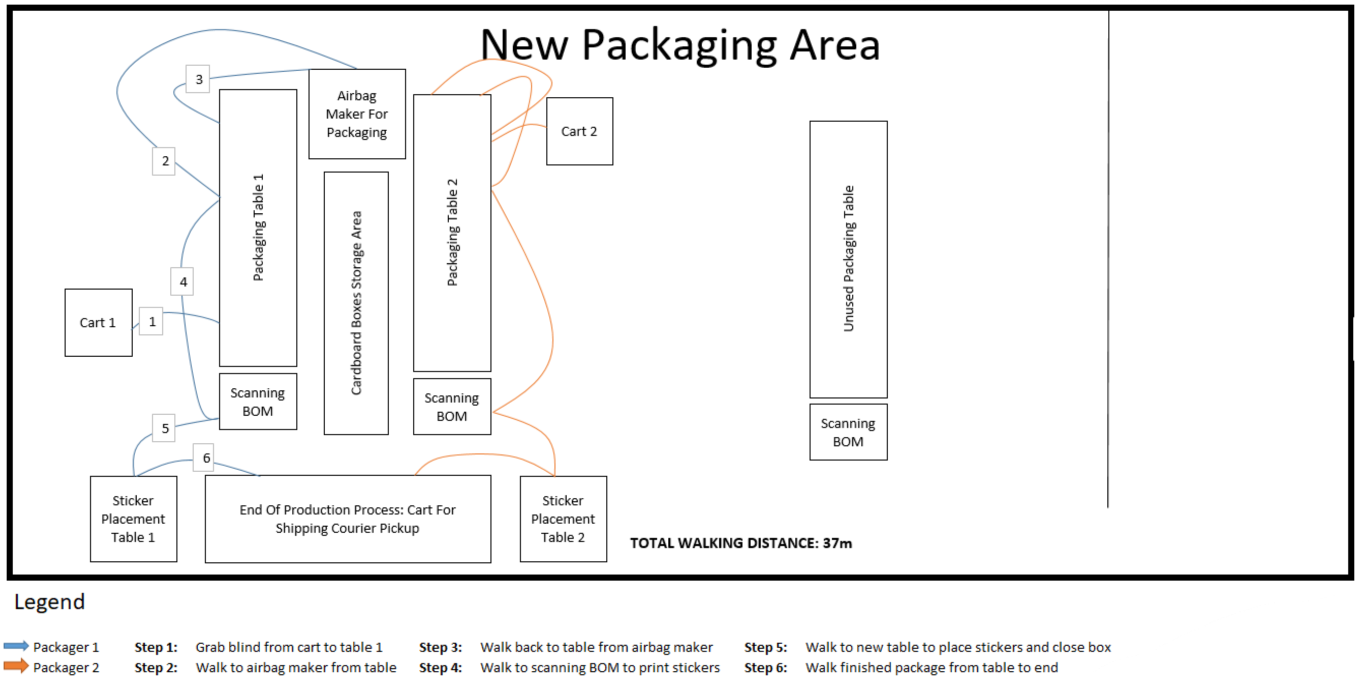


Figure 23: Improved Packaging Spaghetti Diagram

The new layout for the packaging workstation reduces the total walking distance, as can be seen in figure 23, a 45,59% reduction. Table 10 shows the current versus new walking distance, and the number of steps taken by the packaging employee.

Table 10: Packaging Walking Distance & Steps Current vs New (Solution 2)

Current Walking Distance	New Walking Distance	Current Number of Tasks	New Number of Tasks
68 meters	37 meters	8	6

Similar to the previous solution, the steps required to produce a roller blind at the packaging workstation reduces down to six steps, from eight steps. This is because of the placement of the box racks, eliminating the long walk to the cardboard storage box area, and moving the airbag maker closer to both workstations. Additionally, the walking path is changed, because of the newly introduced tables.

The new layout reduces the time spent on NVA process for looking for packaging: 21,43% to 2,94%%. It also reduces the NVA process time of making the box form 11,90% to 0%.

Moreover, making the airbags for packaging consisting of walking to the machine and back, and waiting for the airbags to be made. Since the walking is reduce, it saves 15 seconds, dropping the NVA process times from 29,41% to 22,58%. Finally, the new tables reduce the time walking back to the packaging table, which takes three seconds when measured.

With these improved times, table 11 shows the impact on the production output.

Table 11: New Production Output Solution 2 Packaging Workstation

Current Packaging Workstation Cycle Time (mm:ss)	Future Packaging Workstation Cycle Time (mm:ss)	Current Yearly Production Output Packaging Workstation	Future Yearly Production Output Packaging Workstation
02:47	02:21	41.389	49.021

5.2 Overall Workstation Solution

This section lays out two more solutions which are not for specific workstations, but targeted towards many workstations.

5.2.1 Solution 3: Cart System Optimization

Problem addressed: The cart system

Description: Currently, the cart system at KSA is optimized in a way which tries to balance the flow between the workstations. During observation of the production process and after analyzing the production times, it was clear that the carts are either pushed or pulled by the workstation that has a shorter cycle time. For example, the carts are pushed from the sawing to the fabric cutting, since the cycle times are higher for the fabric cutting. But, the quality inspection workstation pulls the carts from the assembly workstation, since quality inspection has a lower cycle time than the assembly.

The third solution aims to reduce (eliminate in some stations) the NVA time which is spent on moving the carts from one station to the next, or pulling the carts. The solution includes purchasing and implementing automated guided vehicles (AGV) at KSA. AGV's can be programmed to follow a certain path, which is outlined with tape on the floor, as shown in figure 24.

Figure 24: Automated Cart System. Adapted from https://movexx.com/nl/9-manieren-waarop-automatisch-geleide-voertuigen-het-goederentransport-efficient-maken/

As mentioned previously, KSA have been using the cart system for a long time now, so completely removing it may cause problems for the employees. The AGV's will therefore still utilize the cart system, but they will tug or push these carts in place of the workers. For this solution to work, each workstation will have a designated area in which the employee places the cart with the finished item in it, then the AGV will automatically pick the carts up when ready, while the employee can start working on the next products. A total of five AGV's will be needed if the whole solution is used. One between the sawing and fabric cutting workstations. Then another one between the fabric cutting and both the pocket welding and material gathering area. The AGV can be programmed so it knows which path to follow, in case pocket welding is needed. Another AGV is then needed between the material gathering station and the assembly station. Then, another one between the assembly and quality inspection stations, and finally, an AGV between the quality and bubbling workstations. Since packaging and bubbling are already very close, the cart does not need to be moved between them, so an AGV is not needed.

Costs: 5 new carts

= 3500 * 5

= **17.500 euros**

Expected Benefits:

1. Less walking time for employees since the cart is not pushed by them anymore

2. More time put into VA processes, increasing the production output

A test was conducted to measure the time it takes for employees to push carts to the designated area where robots would theoretically pick them up. Due to the unavailability of the robots for purchase and testing, this approach was used to estimate time savings.

The results are presented in table 12 below, which shows the time saved per affected workstation, current NVA process percentages, projected NVA process percentages if the solution is implemented, and the maximum roller blind output per affected workstation. Note that the maximum output is theoretical except for the fabric cutting machine, which sets the annual production pace as the bottleneck.

Table 12: Maximum Output Workstations From Solution 3

Workstation	Time Saved	Current NVA From Moving Cart	Future NVA From Moving Cart	New Cycle Time (Retail & Project)	Maximum Roller Blind Yearly Output Workstation
Sawing	30 s	12,89%	8,35%	01:52	61.714
Fabric cutting	10 s	3,70%	0%	03:58	29.042
Gathering materials	20 s	38,46%	11,11%	03:02	37.978
Assembly	25 s	100%	100%	02:33	45.176
Quality	40 s	45,45%	14,29%	01:54	60.631
Bubbling	30 s	100%	100%	02:03	56.195

The AGV solution significantly reduces NVA times across most workstations, thereby increasing efficiency and potential output. However, the fabric cutting workstation remains the bottleneck and sets the pace for annual output. Therefore, this solution must be combined with others to increase the fabric cutting workstation's output to fully address production constraints.

This solution utilizes process technology in order to make the production process more efficient, so it has some advantages and disadvantages. The advantages are the increased efficiency, since the NVA times are reduced for some workstations, allowing more VA time. Another advantage is the ease of getting used to the new system, since the cart system will remain, the employees do not need to be change the way they work, they only need to push the cart to a closer spot. The disadvantages however are that it is not a full solution, it needs to be combined with other solutions to increase the output. Another disadvantage is regarding safety concerns. Looking at the three questions presented in chapter 3.3 in the literature review regarding process technology, introducing such a technology can cause problems within the production process. The robots may cause safety concerns due to congestion in the production area. This can be especially dangerous when an employee is carrying a heavy object.

5.2.2 Solution 4: Use Unused Infrastructure

Problem addressed: Startup inefficiencies

Description: The fourth solution includes using the workstations/tables which are currently available at KSA but are not being used. This solution applies to the following workstations: assembly, inspection, bubbling, packaging. Moreover, the material gathering workstation can also implement this solution by hiring more employees to prepare the materials.

This solution would be easy to implement, since the current layout of KSA and spacing available already accounts for this unused infrastructure. There are already six tables at the assembly for example, so the infrastructure is there, just not the man-power.

Costs: Varies

The costs of this solution depend on how many workers are hired for each workstation. This will be calculated in the next chapter as a solution on its own, and combined with other solutions.

Expected Benefits:

1. Higher production output from extra labor
2. Higher capacity utilization

This solution maintains the current setup but increases staffing levels to utilize all available workstations. Some workstations have tables ready for more employees but are not currently in use. Specifically, the assembly area has six tables set up, inspection has three, bubbling has two, and packaging has three. These tables are ready to be used and only require additional employees. Moreover, there is no limit for the number of employees that could work at the material gathering workstation.

Since it is not possible to hire more workers to test the solution, this solution is tested based on theoretical numbers from the ERP system. Since the production times are known, and the available working time per year is also known, these calculations can be made.

The production times remain the same for both retail and project orders. The average cycle times for the workstations benefiting from this solution reduce significantly, increasing their annual output. The maximum output calculations account for the differences in production times between project orders and retail orders. Table 13 shows the theoretical maximum output per workstation (which can hire more employees), depending on the number of extra staff hired.

Table 13: (Theoretical) Maximum Output Workstations With Extra Employees With Costs

Workstation	Current Number of Employees	Future Number of Employees	(Theoretical) Maximum Output per Year Per Workstation	Yearly Additional Costs (EUR)
Material gathering	**2**	**-**	**34.217**	**-**
	-	**3**	**51.325**	**30.000**
	-	**4**	**68.435**	**60.000**
Assembly	**2**	**-**	**38.831**	**-**
	-	**3**	**58.247**	**30.000**
	-	**4**	**77.662**	**60.000**
Quality inspection	**2**	**-**	**45.000**	**-**
	-	**3**	**67.324**	**30.000**
Bubbling	**1**	**-**	**45.176**	**-**
	-	**2**	**90.352**	**30.000**
Packaging	**2**	**-**	**41.389**	**-**
	-	**3**	**62.083**	**30.000**

The theoretical maximum output of the workstations could reach 60.000 roller blinds per year. However, the fabric cutting workstation can only produce 27.870 roller blind fabrics per year. Thus, this solution must be combined with other solutions to fully address the bottleneck at the fabric cutting stage.

According to table 11 above, the staffing requirements to reach 60.000 roller blinds per year would cost 210.000 euros per year, and would be as follows:

Material Gathering: 4 employees

Assembly: 4 employees

Quality Inspection: 3 employees

Bubbling: 2 employees

Packaging: 3 employees

The two advantages for this solution are the cost-effective infrastructure and the immediate implementation. Since the tables are already there, they are ready-to-use. There is also no need of purchasing new machines. The two disadvantages from this solution is the high labor costs, and that it is an incomplete solution. Once again, this solution does not benefit the fabric cutting table output, so it must be combined with another solution.

5.3 Fabric Cutting Improvement

This final section of the chapter comes up with three different solutions which could solve the issue of the high fabric changeover times.

5.3.1 Solution 5: Fabric Roll Changing Adjustment

Problems addressed: Fabric changeover time, startup inefficiencies

Description: This solution was made together with two of the fabric cutting table employees during a brainstorming session.

The fifth solution's goal is to reduce the fabric changeover times by shifting processes from an internal activities process to an external activities process. As mentioned previously, changing the fabric consists of four steps. These steps can be broken down further into six activities. First the employee identifies the needed roll from the racks which are set-up by the warehouse employees, shown in figure 25. Then, they pick the roll up using "the giraffe" vehicle. Following that, they drive the vehicle to the cutting table and then place the roll on the fabric cutting table. Once done cutting, the roll is taken out and then put away.

Figure 25: Racks Holding Required Fabrics For the Day

Solution five is for KSA to use a special table (will be referred to as the changeover table), which can hold fabrics, instead of using these racks, where the employee must spend time locating the roll and moving it. The changeover table already exists, shown in figure 26.

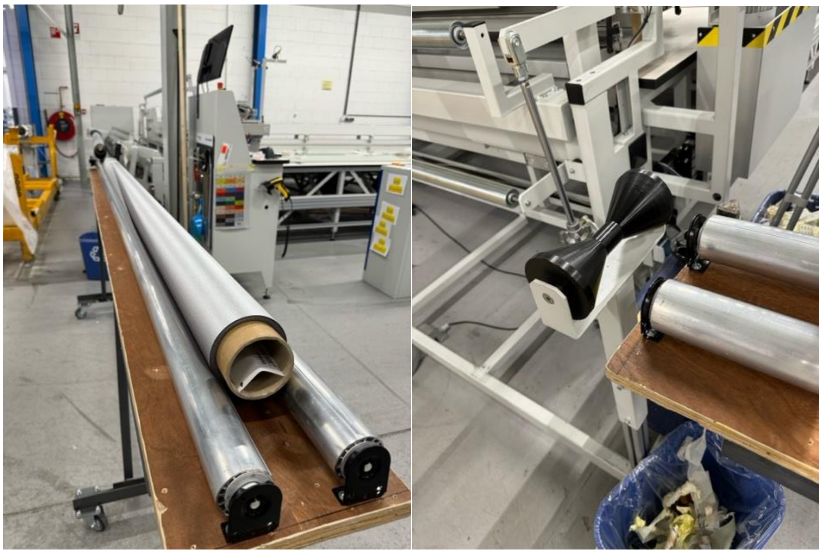


Figure 26: Hand-made Fabric Holding Table (Left). Close-up Table to Fabric Feeder (Right)

Although this table exists, it is not being used by KSA. The changeover table can hold one fabric roll at a time. As aforementioned, there are currently an average of 62 fabric roll changes per week, approximately 12-13 fabric rolls per day. So, **the changeover table can be adjusted to hold four fabric rolls at once, by putting four table tops next to each other, as shown in figure 27. Another option would be to make a rotating paternoster, which would also hold four fabrics at once, shown in figure 28.** Then, when a fabric roll needs to be put onto the fabric cutting table, the employee can push the fabric roll onto the fabric roll holder on the cutting table, without the need of searching for it. Once the fabric roll needs to be changed, they can pull it out onto the empty rack (which had the roll on it originally), adjust the changeover table, and then push the new fabric onto the fabric roll holder. The fabric feeder on the right picture in figure 26 is already placed on the machine, so it can still be used with the tables from figures 27 and 28.

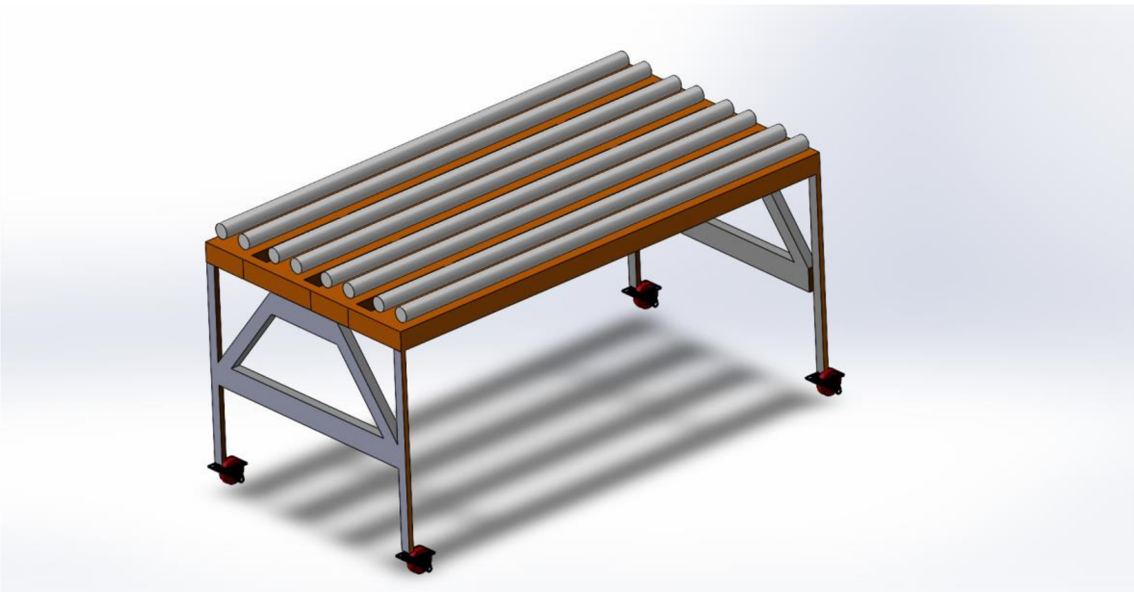


Figure 27: Solution 5 Modelled SolidWorks Changeover Table

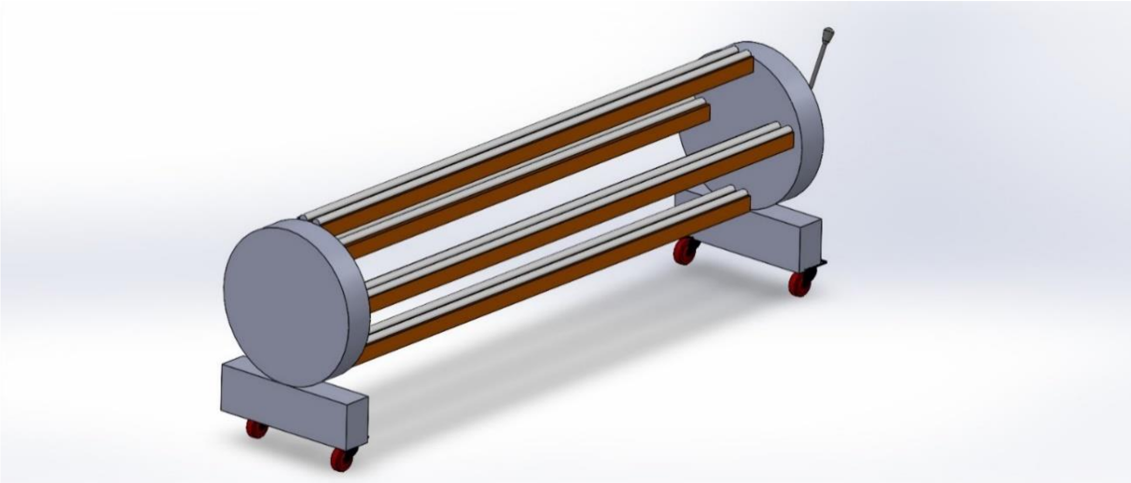


Figure 28: Solution 5 Modelled SolidWorks Rotating Changeover Table

With this solution, the warehouse worker who currently sets-up the fabrics on a rack close to the fabric cutting table will instead place the required fabrics for the upcoming four orders on the changeover table. Then, before the employee breaks (they have three breaks), they will place the upcoming four fabrics for the next orders, since the warehouse workers break is at a different time. **This solution will not introduce any complexities to the current system for the warehouse workers since the same time they currently spend on putting the rolls can be switched to the new method of placing the rolls on the new tables.** Moreover, once the existing racks holding the fabrics are removed, there will be more than enough space to put the changeover table next to the cutting table.

This solution reduces the fabric changeover times for regular fabric rolls, but not jumbo rolls. To solve the issue with jumbo rolls, a metal structure can be used and placed close to the fabric cutting table as well. This structure already exists, and is shown as figure 29 below.

Figure 29: Jumbo Roll Structure Holding It

Currently, when a jumbo roll is needed (one time per day on average), the fabric table employee uses a forklift to lift this structure close to the table, and then they use a special carrying tool to carry the jumbo roll onto the structure. However, for this solution, this can be done in advance and always kept behind the fabric cutting table, since it does not hinder changing the normal fabric rolls with the changeover table.

Costs: Making the table

= 1.000 euros

The current changeover table which can hold one fabric roll costed 170 euros to produce. A new one would cost more, since a stronger metal structure may be needed to hold the weight of four fabric rolls at once. Hence, the price of 1.000 euros is a rough estimate.

Expected Benefits:

1. Shorter fabric changeover time

This solution was tested using the current table which holds one fabric. **The changeover process was done in 45 seconds, reducing the NVA process time from 70,37% to 36%.** This is because half of the activities required to change the fabric roll changed from internal to external activities, shown in table 14.

Table 14: SMED State Changes Solution 5

Activity	Current State (External/Internal)	Future State (External/Internal)
Walking towards and identifying location of roll on rack	Internal	External
Picking up roll with "the giraffe" vehicle	Internal	External
Driving "the giraffe" to the fabric cutting table	Internal	External
Placing roll on the fabric cutting table	Internal	Internal
Taking roll out of fabric cutting table	Internal	Internal
Putting the empty roll away	Internal	Internal

Reducing the changeover process increases the yearly production, shown in table 15.

Table 15: New Production Output Solution 5 Fabric Cutting Workstation

Current Fabric Cutting Workstation Cycle Time (mm:ss)	Future Fabric Cutting Workstation Cycle Time (mm:ss)	Current Yearly Production Output Fabric Cutting Workstation	Future Yearly Production Output Fabric Cutting Workstation
04:08	03:10	27.870	34.441

Although this solution does not reach the target of 60.000 roller blinds per year, it increases the production output by 23,58%, for a small price.

5.3.2 Solution 6: Automatic Fabric Changer

Problem addressed: Fabric changeover time

Description: A robot storage system from ASCO (a Dutch company) which fully automates the fabric roll handling, as shown in figure 30.

.

Figure 30: ASCO Robot Storage System. Adapted from ascobv.com/portfolio/handling-storage/

With this system, each fabric roll is stored on a shaft and placed on a rack within the system. A robot then transports the rolls from any rack location to the cutting table. The robot storage system's computer can be programmed by the cutting table employee such that the next required fabric roll for an order can be prepared and ready to be put on to the fabric cutting table while a fabric is being cut. The preparation of a new roll while the previous one is being processed at the cutting table can save a tremendous amount of time when changing the fabric rolls. ASCO claims that this storage facility is perfect for processes that require short changing times between fabric rolls.

There are similar products in the market, however, the fabric cutting table currently being used at KSA is from ASCO, so it is much easier to integrate the robot storage system with the fabric cutting table.

One problem with this solution is that the robot storage system cannot handle jumbo rolls, and for certain project orders, using jumbo rolls is necessary. For this reason, this solution is also combined with purchasing a new cutting table from ASCO. With this solution, there will be one line for project orders (the current cutting table), and another line for retail orders, which will make use of the robot storage system.

Costs: Two new employees (yearly) + Fabric cutting table + Robot Storage System + Extra energy costs (yearly) + Depreciation costs

= (2500 * 2*12) + 250.000 + 250.000 + 10.300

<u>Yearly costs</u>: New employees (60.000) + Extra energy costs (10.300) + Depreciation costs (24.000)

= 94.300 euros/year

<u>Fixed cost:</u> Fabric cutting table (250.000) + Robot storage system (250.000)

= 500.000 euros

Salaries at KSA differs. It is calculated based on the employees age, and the number of workstations they are capable of working in. The average salary is 2500 euros per month.

The extra energy costs incurred will be for a new cutting table and the robot storage system. There is no information on how much kWh of electricity the robot storage system consumes, so it will be assumed that it consumes the same amount of kWh as the cutting table. Currently, KSA pays 0,1109150 euros per kWh, plus a 21% BTW. Based on the month of April of 2024, the daily consumption of the fabric cutting table is around 149,9 kWh, costing 5.150 euros yearly. So, both a new fabric cutting table and a robot storage system would cost double of that, according to the assumption.

To calculate the depreciation costs, the straight-line depreciation formula is used (Rao, 2023):

$$Depreciation\ Expense = \frac{(Asset\ cost - Salvage\ value)}{Useful\ life}$$

The salvage value is the estimated value that the machines can be sold for at the end of their life. The fabric cutting table and the robot storage system cost 250.000 euros each, and their salvage value is assumed to be 70.000 euros, with a useful life of 15 years. So, the depreciation costs per machine are 12.000 euros per year.

Expected Benefits:

1. Shorter fabric changeover times
2. Higher production output from second cutting table
3. Two separate lines for project and retail orders

Implementing this solution introduces a new fabric cutting line at KSA, resulting in two fabric cutting tables: one dedicated to retail orders and the other to project orders. For project orders, the production time remains at 02:42 per blind, since the current line will still be used for fabric cutting. But now, all of the yearly production hours are only shifted to project orders, which increases their output to **approximately 42.666 blinds annually, only for project orders**. For retail orders, the addition of an automatic fabric storage system significantly reduces the total time spent on fabric cutting, which previously took an average of 03:10 when observed (although it is estimated to take five minutes). According to ASCO, the fabric storage system can drastically reduce the roll change time to 15 seconds by preparing the next fabric order while the current one is being cut. This improvement reduces the roll change time by 02:55, decreasing the NVA time from 70,37% to 5,56%. With this reduction, the time to produce one retail blind drops from 07:02 to 4:07. Considering the available yearly production time, **the retail order line can produce approximately 27.983 roller blinds annually**.

This solution can meet the total demand with a combined capacity of 70.649 blinds per year at the fabric cutting tables. However, this shift in efficiency will move the bottleneck to another workstation. To fully address KSA's production constraints, this solution should be combined with additional improvements.

The advantages of using this solution would be having two separate lines for fabric cutting. This ensures that if one fabric cutting table breaks down, the entire business operation does not come to a halt. However, the biggest disadvantage to this solution is the cost. It is the most expensive solution presented to KSA, and it is currently not a feasible investment for the company. However, it can benefit KSA in the future if they intend to produce even more roller blinds than 60.000 per year.

5.3.3 Solution 7: Extra Shift Fabric Cutting

Problem addressed: Fabric changeover time

Description: The seventh solution suggests KSA to keep their current fabric workstation process unchanged, but to add an extra 7,5 hour shift for the fabric cutting table, which consists of two employees.

If the seventh solution is implemented, then there will be a second shift from 16:15pm till 00:30am. During this second shift, only the fabric cutting workstation will be working, so there will be WIP created by sawing during the first shift, such that the fabric cutting employees can cut the required fabrics for this WIP. During the extra fabric cutting shift, one employee will cut the fabrics, and the other will roll the fabrics onto the sawed tubes. Then, the rolled fabric will be placed on a cart as a buffer for the assembly workstation. The next morning, during the normal shift, the assembly will then have a buffer of roller blinds to be assembled.

One problem with this is that the current yearly capacity of the sawing workstation is 48.676 roller blinds, so if solution seven is chosen, the fabric cutting table during the second working shift will never reach 100% capacity. For this reason, it is best to combine this solution with other solutions, such as the first solution, which reduces the NVA times for the sawing workstation. Moreover, if this solution is chosen and combined with solution five (fabric changeover table), then three fabric changeover tables need to made, instead of one, since the warehouse workers will not be present during the second shift.

Costs: Extra yearly shift costs + Extra yearly energy costs

= (2823 * 2 * 12) + 4.950

= **72.702 euros/year**

To calculate the costs here, the extra energy costs are calculated in a different way to solution six. The company that provides energy to KSA charges 0,0872240 euros per kWh during the off-peak hours, which are between the hours of 23:00 and 07:00, so of the second shift, an hour and a half are within these off-peak hours, reducing the energy costs. Regarding the shift costs, working after regular hours earns the employee 12,9% bonus, so around 2823 euros per month.

Expected Benefits:

1. Higher production output from cutting table

This solution maintains the current fabric cutting setup but introduces an additional shift to increase production capacity. The production times for both project and retail orders at the fabric cutting workstation remains the same, at 02:42 per blind, and 07:02 for retail orders.

The annual output following this solution will be double the current annual output of the fabric cutting workstation, allowing for the production of 55.740 blinds per year. However, this increase will likely shift the bottleneck to another workstation, hence it needs to be combined with another solution.

The advantages to this solution are that it does not require an initial investment, and that it is a more affordable option for KSA when compared with solution six. This solution also increases the fabric cutting table utilization rate. However, there are three disadvantages to this solution. The first disadvantage is that the target of 60.000 roller blinds per year is still not reached. The second disadvantage is that this solution poses operational risk. If the fabric cutting table encounters issues, then the production will halt entirely. The final disadvantage to this solution are the labor challenges. It is much more difficult to hire workers for a second shift, despite a 12,9% salary bonus for working the second shift.

5.4 Combination of Solutions

Most of the solutions focus on optimizing single workstations, with the exception of the cart system optimization solution, and the unused infrastructure solution. So, these solutions increase the output of the targeted workstations, but may not collectively increase the production output, unless it is for the fabric cutting workstation (since it is the current production bottleneck).

There are seven different solutions, but 5! combinations of solutions (because there are three for the fabric cutting table which will not be combined), totaling 31 different combinations, so the solutions are tested together based on how they can complement one another with regards to fixing the new bottlenecks once they are implemented. Solution six is excluded as it is too expensive for KSA.

5.4.1 Solutions 4 & 5 Combined

The fifth solution, which makes use of the changeover table for changing the fabric rolls, results in the production of 34.441 roller blinds per year. However, since the material gathering workstations' maximum output per year is 34.217 roller blinds, to reach the full potential output of the fifth solution, an additional employee needs to be hired for the material gathering workstation. This would increase the material gathering workstations' maximum yearly output to 51.325. However, the fabric cutting table will still be the bottleneck in this case.

The total cost of the fourth and fifth solutions combined is 30.000 euros per year and an initial investment of 1.000 euros, with a maximum yearly output of 34.441 roller blinds. Hiring the new material gathering employee only increases the yearly production output by 224 roller blinds, for the cost of 31.000 euros, hence implementing solution five alone is a better and cheaper option for KSA.

5.4.2 Solutions 1, 2, 4, 5 & 7 Combined

The first two solutions do not increase the output of roller blinds at KSA, because the fabric cutting output needs to increase.

Although the fifth solution increases the output of the fabric cutting table, it is nowhere close to 60.000 blinds. The seventh solution also does not reach 60.000 roller blinds/year, but it does require an additional high yearly cost. For this reason, the fifth and seventh solution are to be analyzed when combined together, then the fabric cutting table will not be the bottleneck anymore.

To analyze the impact of combining the fifth and seventh solutions, the fifth solutions' output is doubled, since implementing the fifth solution, and then doubling the available hours for fabric cutting will double the output from the fifth solution. So, both solutions combined result in the ability for the fabric cutting table to cut 68.882 roller blinds per year. For both of these solutions to be combined, the fifth solution (changeover table) will require the making of three changeover tables, compared to one, which will cost 3.000 euros instead of 1.000 (mentioned earlier), since there will be no warehouse employees to replace the fabrics. With three tables, the twelve fabrics for the changeovers can be ready.

Now, the new bottleneck is the material gathering workstation. Using solution four's output, an additional employee can be added, increasing the capacity for material gathering to 51.325 per year. Following that, the next bottleneck is the assembly workstation. Once again, an additional employee can be hired, since the table is already set-up, and the capacity then becomes 58.247. Then, the second solution is implemented, since the bottleneck now is the packaging. With this solution, the output of packaging becomes 49.021 per year. The quality inspection now becomes the bottleneck, with a capacity of 45.000 roller blinds per year. If another employee is added, the new bottleneck becomes bubbling, at 45.176 roller blinds per year. Adding one more employee there makes the new bottleneck sawing, which is solved through the use of the first solution. The next bottleneck becomes packaging again. Now, the output of the whole process is 49.021 roller blinds per year. In order to reach the 60.000 target, table 16 below shows the full steps required, when combining these five solutions.

Table 16: Reaching 60k Output Bottlenecks and Changes Required 5.4.2

Change	New Capable Output in Location Per Year	New Bottleneck
1. Solutions five and seven combined	Fabric cutting: 68.882	Material gathering
2. Additional employee material gathering	Material gathering: 51.325	Assembly
3. Additional employee assembly	Assembly: 58.247	Packaging
4. Implement solution 2	Packaging: 49.021	Quality inspection
5. Additional employee quality inspection	Quality inspection: 67.324	Bubbling
6. Additional employee bubbling	Bubbling: 90.352	Sawing
7. Implement solution 1	Sawing: 64.598	Packaging
8. Additional employee packaging	Packaging: 73.531	Material gathering
9. Add one more employee gathering materials (total 4)	Material gathering: 68.435	Assembly
10. Add one more employee assembly (total 4)	Assembly: 77.662	Sawing

With all of these changes. The production output becomes 64.598 roller blinds per year. This solution requires hiring seven new employees, running a second shift for the fabric cutting table (with two more employees), and more, costing over 282.702 euros/year, and requiring an investment of 3.720 euros to implement. For this reason, an analysis is made to see which change (from table 15) to stop at. The analysis is done by graphing the cumulative output from each solution, with the cumulative cost of implementing the solutions, shown in figure 31. <u>This diagram only takes the yearly costs into account, and not the fixed investment costs.</u>

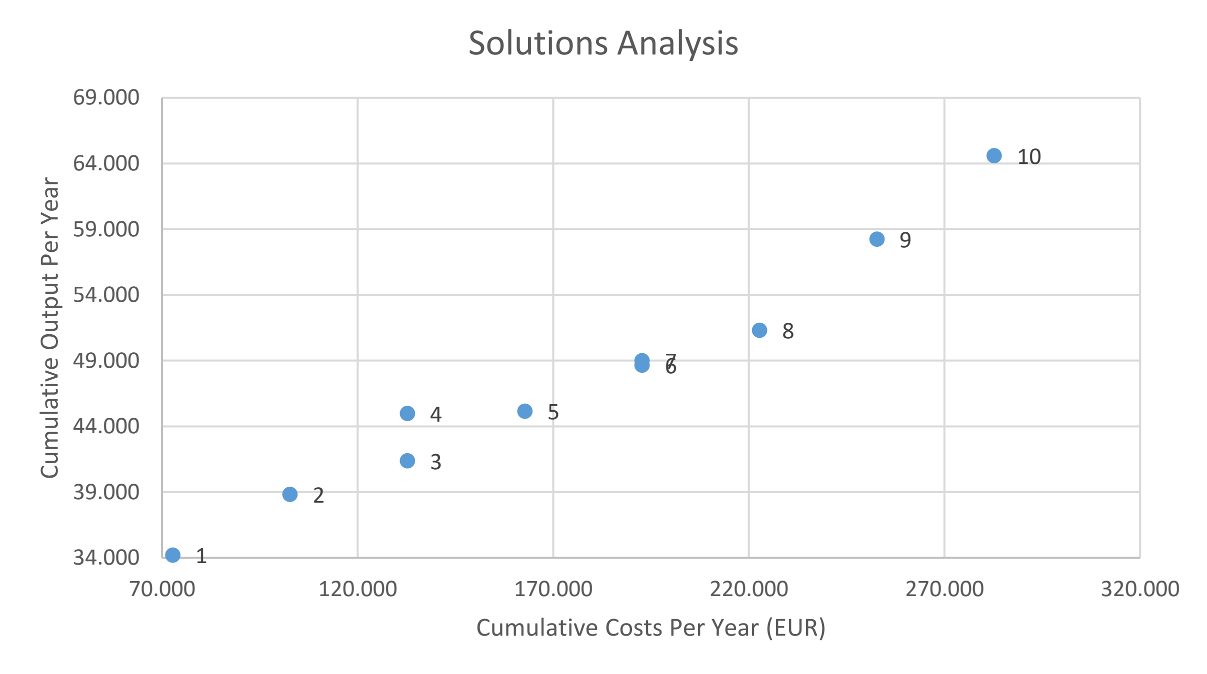


Figure 31: Analysis of Solutions Scatter Plot 5.4.2

The points with the higher slopes to the next point show that the solution is beneficial in terms of a higher output with a lower cumulative cost. Looking at the figure, it is clear that the fifth change of adding an additional quality inspection employee has the least impact on the production output, the new employee can only increase the output by 176 roller blinds per year, from 45.000 roller blinds to 45.176, for a cost of 30.000 euros per year.

Based on this diagram, the best solution which combines solutions one, two, four, five, and seven together is to make the first four changes shown in table 15. **This will cost 132.702 euros per year and require an investment of 1.496 euros, increasing the production output to 45.000 roller blinds per year.**

Furthermore, once demand reaches 60.000 roller blinds, then all ten changes can be made, costing a total of 282.702 euros per year, and increasing the production to 64.598 roller blinds per year.

For the cost of 282.702 euros per year, and an initial investment of 3.720 euros, it could seem like solution six (automatic fabric changer) is not so expensive after all, however, if solution six is implemented, there will still be other bottlenecks in production, and the total cost per year will be much higher than 282.702 euros. The initial investment will also be 500.000 euros.

5.4.3 Solutions 1, 2, 3, 4, 5 & 7 Combined

Now the third solution (AGV) is also tested with the previous combination of solutions. That is done since for some workstations, solution three may be cheaper to implement over hiring a new employee.

The same process is done here as the previous analysis, where the changes from the solutions are made in table 17 below, and the new bottleneck is identified.

Table 17: Reaching 60k Output Bottlenecks and Changes Required 5.4.3

Change	New Capable Output in Location Per Year	New Bottleneck
1. Solutions five and seven combined	Fabric cutting: 68.882	Material gathering
2. Additional employee material gathering	Material gathering: 51.325	Assembly
3. Solution three between material gathering and assembly	Assembly: 45.176	Packaging
4. Implement solution two	Packaging: 49.021	Quality
5. Solution three between assembly and quality	Quality: 60.631	Bubbling
6. Solution three between quality and bubbling	Bubbling: 56.195	Assembly
7. Additional employee assembly	Assembly: 67.764	Sawing
8. Implement solution one	Sawing: 64.598	Packaging
9. Additional employee packaging	Packaging: 73.531	Material gathering
10. Additional employee material gathering (4 total)	Material gathering: 68.435	Bubbling
11. Additional employee bubbling	Bubbling: 84.292	Quality control

With all of these changes, the maximum yearly output becomes 60.631, the new capacity of the quality control station.

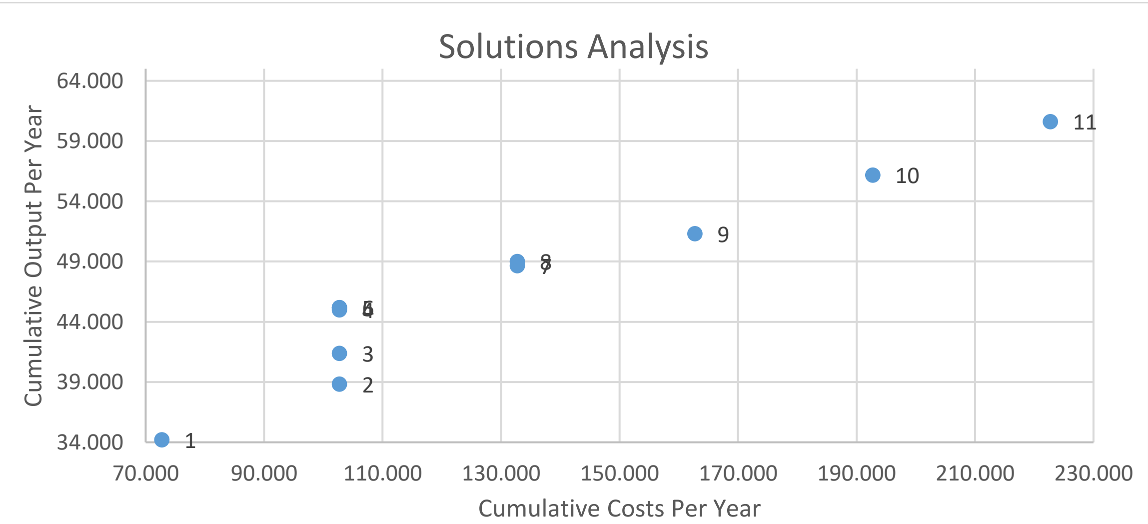


Figure 32: Analysis of Solutions Scatter Plot 5.4.3

A similar diagram to the previous sub-section is made, highlighted as figure 32 above. Once again, the changes with the lowest slopes between them are the least ones impacting the production output when compared to the price. The fixed costs are not considered in this diagram. **It is not very clear, but according to the figure, change number six to seven has the lowest slope, hence the sixth change should be the last in terms of higher benefits compared to costs, which sets the maximum capacity to 45.176 roller blinds per year, with a yearly cost of 102.702 euros, and an initial investment of 11.996 euros.**

If all 11 changes are made, the total cost 222.702 euros per year, with an initial investment of 12.220 euros. The output is then 60.631.

Cost wise, this solution is better than the previous combination of solutions which was tested in section 5.4.2. However, with the combination of solutions analyzed in section 5.4.2, the output is 3.967 higher than this solution, but for a much higher yearly cost.

5.5 Chapter Summary

The fifth chapter proposes various solutions to address the inefficiencies identified in the fourth chapter, focusing on specific area re-designs, overall workstation improvements, and enhancements in the fabric cutting process. Each solution is analyzed for its potential impact on production capacity and cost-effectiveness.

The first set of solutions involves redesigning the workstation layouts to minimize unnecessary movements. For the sawing workstation, the proposed redesign aims to improve material flow and reduce worker movement by reorganizing the placement of tools and materials. Similarly, the packaging workstation layout is redesigned by optimizing the positioning of packaging materials and finished products. Another significant solution is optimizing the cart system used for material handling. The proposed optimization involves implementing AGVs to push the cart system, enhancing the internal transport of materials. Utilizing unused infrastructure is another proposed solution. KSA has extra tables that are currently unused. By using these tables through hiring more employees, KSA can increase production capacity. For fabric cutting improvements, two main solutions are proposed: adjusting the fabric roll changing process and implementing an automatic fabric changer. The fabric roll changing adjustment involves making and using a fabric changeover table, which significantly reduces the downtime of the fabric cutting table. The automatic fabric changer offers good long-term benefits since it requires purchasing a new fabric cutting table, however, it is currently not feasible as it requires a substantial initial investment. The chapter also explores the feasibility of adding extra shifts to maximize the use of existing infrastructure and labor. All of these solutions are summarized below in table 18, with their theoretical maximum roller blind output per year, where the theoretical maximum output is, the new production bottleneck after implementing that solution, and the real maximum roller blind output per year, when considering the other bottlenecks.

Table 18: Summary of Solutions

Solution	Costs (EUR)	Theoretical Maximum Roller Blind Output per Year	Maximum Output In	Production Bottleneck After Solution	Real Maximum Roller Blind Output per Year
1	224	64.598	Sawing workstation	Fabric cutting	27.870
2	496	49.021	Packaging workstation	Fabric cutting	27.870
3	17.500	29.042	The whole process	Fabric cutting	29.042

4	Varies	Varies	The whole process	Varies	Varies
5	1.000	34.441	The whole process	Gathering Materials	34.217
6	500.000 + 94.300/year	70.649	The fabric cutting workstation	Gathering Materials	34.217
7	72.702/year	55.740	The fabric cutting workstation	Gathering Materials	34.217

The individual solutions are then combined with each other in order to increase the production output of the whole production process, and not just of the selected workstations. The chapter concludes by presenting different combined solutions, each with different implementation costs and production outputs. These five combined solutions are:

1. Implementing the fifth solution of using a fabric changeover table and hiring a material gathering employee.
2. Implement the fifth solution of using a fabric changeover table, add a second shift for the fabric cutting (solution 7), add an employee to the material gathering and the assembly workstations, and re-design the packaging workstation based on the second solution.
3. All of the above (from combined solution 2) plus add another employee to the quality inspection, bubbling, packaging, assembly, and material gathering. Also re-design the sawing workstation based on the first solution.
4. Implement the fifth solution of using a fabric changeover table, add a second shift for the fabric cutting table, purchase and use three AGVs to push the carts between the material gathering workstation and the assembly workstation, the assembly and quality inspection workstations, and assembly to bubbling, implement solution two of re-organizing the packaging workstation, and hire an extra employee for the material gathering workstation.
5. All of the above (from combined solution 4) and hiring one more employee for the material gathering, assembly, packaging, and bubbling. Also, to re-design the sawing workstation as shown in the first solution.

These five combined solutions are presented in table 19 below, with their associated costs and yearly production output.

Table 19: Three Combined Solutions' Output and Costs

Combined Solutions	Costs	New Production Output Per Year
1	30.000 EUR/year + 1.000 EUR Investment	34.441
2	132.702 EUR/year + 1.496 EUR Investment	45.000
3	282.702 EUR/year + 3.720 EUR Investment	64.598
4	102.702 EUR/year + 11.996 EUR Investment	45.176
5	222.702 EUR/year + 12.220 EUR Investment	60.631

6. Recommendations & Implementation Plan

In this chapter, the recommendations which follow the solution analysis are given to KSA, and then an implementation plan is made regarding these recommendations. The goal of this chapter is to answer the following sub-research question: *"What are the best fitting recommendations that can be made to KSA based on the results of the previous chapters?"* **Chapter 6.1** starts by laying out the recommendations. Then, **Chapter 6.2** is where the implementation plan for these recommendations is shown. Finally, **Chapter 6.3** is the conclusion to this chapter.

6.1 Recommendations

Following the fifth chapter, recommendations are given to KSA based on the analysis of the solutions. There are three recommendations given to KSA. These recommendations should be taken based on time, since the demand is not expected to suddenly double. For this reason, a short-term, mid-term, and long-term recommendation is given.

Short-term recommendation

The first recommendation for KSA is to implement the fifth solution alone, by manufacturing the changeover table such that the fabric changeover time can decrease. This solution increases the production to 34.217, increasing the current production output capacity by 22,77% for an estimated price of 1.000 euros. This recommendation should be done immediately, since it is low-cost to implement, and results in an increase of over 6.000 roller blinds per year.

Mid-term recommendation

The second recommendation is for KSA is to combine the first, second, third, fourth, fifth, and seventh solutions (combined solution 4), with the following seven changes, which include:

1. Making and using the fabric changeover table
2. Adding a second shift to the fabric cutting table
3. Purchasing three AGVs to push the cart between the material gathering workstation and the assembly workstation, the assembly and quality inspection workstations, and quality inspection to bubbling.
4. Re-organizing the packaging workstation, and purchasing two new tables there, according to solution two.
5. Hiring an extra employee for the material gathering workstation

This would result in an output 45.176 roller blinds per year, for the price of 102.702 euros per year, and an initial investment of 11.996 euros. An increase of 62,1% in production output. This recommendation should be followed once demand increases to the 45.000 region, since the demand will likely not increase to 60.000 in a short time.

Long-term recommendation

The final recommendation to KSA is for them to once again combine the first, second, third, fourth, fifth, and seventh solutions (combined solution 5), but with more changes, which includes:

1. The same recommendations from the second recommendation
2. Hiring one more employee for the material gathering (total 4), assembly, packaging, and bubbling
3. Re-designing the sawing workstation, and giving the new instructions to the warehouse workers.

This recommendation results in an output of 60.631 roller blinds per year, for an initial investment of 12.220 euros, and a yearly cost of 222.702 euros. However, if the second recommendation is implemented first, and then the third, then the additional cost will be 224 euros initially, and 120.000 euros per year, increasing the output from 45.175 to 60.000. The third recommendation should be implemented once KSA are certain that their demand will reach 60.000. In the case that it does not, then the only investment KSA made is 12.220 euros, since the extra hired employees can always be let go.

6.2 Implementation Plan

An implementation plan is made for each recommendation, which includes a Gantt chart to show the expected tasks to be taken in relation to a time plan.

6.2.1 Short-term Recommendation

The first recommendation which KSA should take in the short-term could take up to two months to implement. Figure 33 shows a more detailed weekly time plan for KSA to follow, within a given time frame. Since this recommendation should be followed immediately, the start date of implementing this solution is now.

The table should be designed in a way that is feasible in terms of materials and cost for KSA. The 3D models presented in chapter five can be used as inspiration. While an employee is designing the table, there should be an internal meeting with the supervisors to discuss the full plan of implementing the solution. Then, after the table is designed, an employee should start to make the table. Concurrently, another meeting should take place between the fabric cutting table employees, where the plan of action should be discussed. In this meeting, the steps of changing the fabric rolls are made clear to the employees. Then, a third meeting with the warehouse employees is needed, to inform them on the new process, and how it impacts their current work. Now, their schedules are changed, as they spend less time putting the required fabrics on a rack, but spend more time replenishing the fabric changeover table with fabric rolls. Following the completion of the fabric changeover table, weekend test runs are to be made in two different weekends. This ensures that the current production process is not hindered, since employees will take some time to get used to the new system. Finally, the current fabric racks should be removed, so that there is enough space for the fabric changeover table.

TASK ID	TASK NAME	START DATE	END DATE	WEEKS	01-jul-24 27	08-jul-24 28	15-jul-24 29	22-jul-24 30	29-jul-24 31	05-aug-24 32	12-aug-24 33	19-aug-24 34	26-aug-24 35	02-sep-24 36
Task 01	Designing the table	01-jul-24	15-jul-24	3										
Task 02	Making the table	15-jul-24	15-aug-24	5										
Task 03	Internal meetings #1	01-jul-24	20-jul-24	3										
Task 04	Internal meetings #2	20-jul-24	01-aug-24	3										
Task 05	Internal meetings #3	01-aug-24	15-aug-24	3										
Task 06	Weekend test runs	17-aug-24	26-aug-24	3										
Task 07	Clear out fabric racks	27-aug-24	28-aug-24	1										

Figure 33: Short-Term Recommendation Gantt Chart

6.2.2 Mid-term Recommendation

The second recommendation which KSA should take in the mid-term (within two years) could take up to 18 months to implement, as shown in figure 34 below. The P's in figure 34 are the phases, and the

T's are the tasks required to complete the phases. For simplicity, the changeover table implementation is placed as a P with no T's, since it requires the same tasks as with the first recommendation.

Because it is unknown how fast the demand at KSA will increase within the coming years as a result of their expansion to the DACH and UK regions, it is assumed that by the beginning of 2026, KSA should be able to produce at least 45.000 roller blinds per year. For this reason, recommendation two is implemented before the start of 2026.

Hiring the employees is done by the HR manager, while the other tasks require the warehouse employees and production employees. The onboarding of employees takes a month at KSA, and searching for an employee could also take a month. Once an employee is hired, they always start work at the beginning of the following month. With regard to the AGVs, once they are programmed and the stickers are placed on the floors, there must be a safety course, since they could potentially injure employees. This safety course can be held by the facilities manager at KSA. Finally, the packaging workstation should be re-designed by moving the items around as specified for the second solution.

TYPE	TASK NAME	START DATE	END DATE	MONTHS
P	**Implementing changeover table**	01-jul-24	26-aug-24	2
P	**Hiring new employees**	01-jan-25	01-jun-25	6
T	Search for material gathering employee	01-jan-25	31-jan-25	1
T	Search for fabric cutting employees	01-jan-25	28-feb-25	2
T	Hire material gathering employee	01-mrt-25	01-mrt-25	1
T	Onboard material gathering employee	01-mrt-25	01-apr-25	2
T	Hire fabric cutting employees	01-apr-25	01-mei-25	2
T	Onboard fabric cutting employees	01-mei-25	01-jun-25	2
P	**Implementing second fabric shift**	01-jun-25	01-jul-25	2
T	Test runs with new employees	01-jun-25	01-jul-25	2
P	**Implementing AGVs**	01-feb-25	01-sep-25	8
T	Purchase three AGVs	01-feb-25	01-apr-25	3
T	Place tape on floors	01-mei-25	01-jun-25	2
T	Program the AGVs	01-jun-25	01-jul-25	2
T	Safety courses for AGVs	01-jul-25	01-aug-25	2
T	Test runs using AGVs	01-aug-25	01-sep-25	2
P	**Re-designing packaging workstation**	01-sep-25	31-dec-25	4
T	Purchase and install two new tables + racks	01-sep-25	01-okt-25	2
T	Move items around	01-okt-25	15-okt-25	1
T	Test runs with packaging employees	01-nov-25	31-dec-25	2

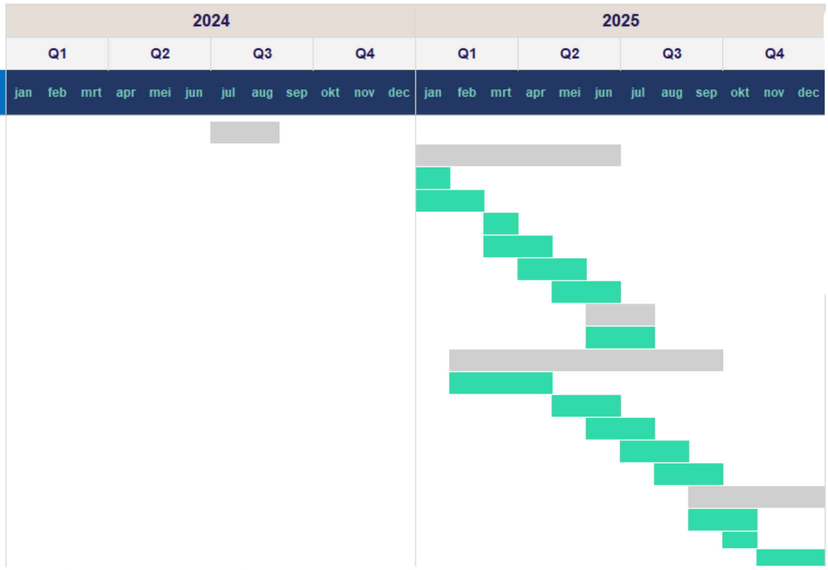


Figure 34: Mid-term Recommendation Gantt Chart

6.2.3 Long-term Recommendation

For the third and final recommendation, which should be made within the upcoming six years, the steps start in 2029, with the goal of fully implementing the solutions by the end of 2029. The assumption taken here is that the demand is 60.000 roller blinds per year by 2030. Figure 35 below shows the full time plan in a Gantt chart. For simplicity, only the new tasks required for the third recommendation are shown in the Gantt chart, since the previous two recommendations should have already been made, and the third recommendation adds capacity from the second recommendation.

The first eight months of the year are to be spent searching for new employees, hiring them, and onboarding them. That is to be done by the HR manager and the onboarding is done by the current employees at the same workstations. Then, the last three months of the year are spent on re-designing the sawing workstation. First, the profiles from the current inventory wall are to be removed, then new racks are installed close to the sawing tables. From there, the warehouse employees will put the new profiles (from the Pareto analysis) onto the new racks. The sawing employees, with the help of the warehouse employees will then move the rest of the items around, as shown in the layout re-design in the first solution of chapter five. Finally, a test run will take place for a month, to ensure there is a smooth transition to the new system.

For a more accurate outcome, a new Pareto analysis should be made before re-designing the sawing workstation, since the demand patterns could change within the coming five years.

TYPE	TASK NAME	START DATE	END DATE	MONTHS
P	**Hiring new employees**	01-jan-29	01-sep-29	9
T	Search for assembly employee	01-jan-29	31-jan-29	1
T	Search for packaging employee	01-jan-29	31-jan-29	1
T	Search for material gathering employee	01-jan-29	31-mrt-29	3
T	Search for bubbling employee	01-jan-29	30-apr-29	4
T	Hire assembly employee	01-apr-29	01-apr-29	1
T	Onboard assemblyemployee	01-apr-29	01-mei-29	2
T	Hire packaging employee	01-mei-29	01-mei-29	1
T	Onboard packaging employees	01-mei-29	01-jun-29	2
T	Hire material gathering employee	01-jun-29	01-jun-29	1
T	Onboard material gathering employee	01-jun-29	01-jul-29	2
T	Hire bubbling employee	01-aug-29	01-aug-29	1
T	Onboard bubbling employee	01-aug-29	01-sep-29	2
P	**Re-designing sawing workstation**	01-sep-29	31-dec-29	4
T	Remove profiles from invetory wall	01-sep-29	15-sep-29	1
T	Move inventory racks to sawing table	15-sep-29	30-sep-29	1
T	Put profiles on new inventory rack	01-okt-29	07-okt-29	1
T	Move rest of items	10-okt-29	10-nov-29	2
T	Test runs with sawing employees	01-dec-29	31-dec-29	1

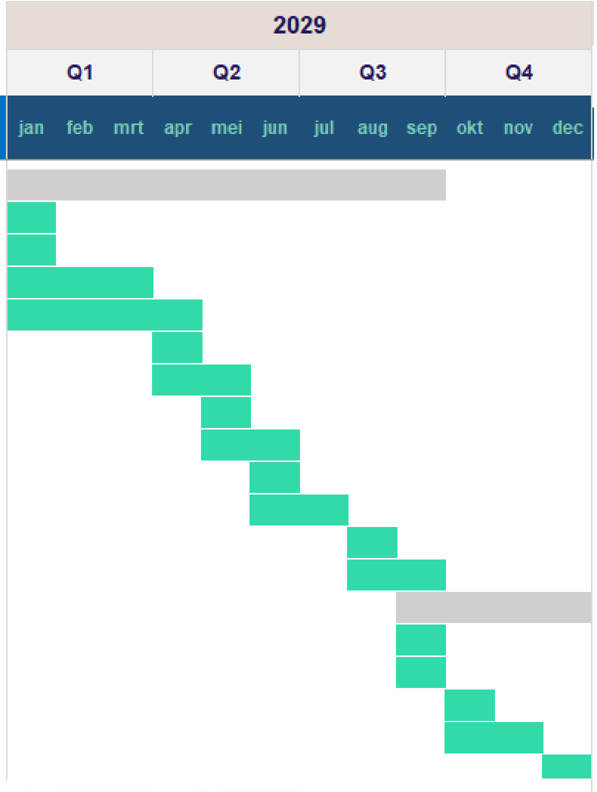


Figure 35: Long-term Recommendation Gantt Chart

6.3 Chapter Conclusion

The sixth chapter presents the recommendations and an implementation plan based on the solution analysis from the previous chapter. The chapter begins by proposing three sets of recommendations categorized into short-term, mid-term, and long-term strategies. In the short term, it is recommended to implement a fabric changeover table to reduce changeover times, which can significantly increase production output at a minimal cost. For the mid-term, a combination of solutions including additional shifts, optimizing the cart systems using AGVs, and re-designed workstations is suggested to further increase production. Long-term recommendations focus on hiring additional employees (in addition to the mid-term recommendation), and re-designing the sawing workstation, based on solution one. The chapter concludes by providing a detailed implementation plan to help KSA gradually integrate these recommendations into their production process. The short-term recommendation should take two months to implement while the mid-term and long-term recommendations should each take a year to implement.

7. Conclusions

In this chapter, the conclusions from this research are given. **Chapter 7.1** starts by concluding the research, followed by **Chapter 7.2**, which discusses the limitations within the context of this research. **Chapter 7.3** then connects these limitations with future opportunities for research. Finally, **Chapter 7.4** discusses the contribution to theory and practice as an outcome of this research.

7.1 Conclusions

KSA is faced with the problem of meeting expected future demand, since they have had a steady demand over the last years, and would like to expand into the UK and DACH regions. Currently, KSA believes that their production capacity is 30.000 roller blinds, and they would like to increase that number to 60.000 roller blinds produced per year. The goal of the research was to answer the following research question:

"What are the best ways for KSA to successfully scale up their roller blinds production to 60.000 per year, by reducing their production inefficiencies, while seeking low-cost approaches?"

Sub-research questions were made, which break down the main research question. These sub-research questions shape the structure of this thesis, and were identified in the first chapter.

Sub-question 1: *"What does the current roller blind production process look like at KSA, and how are the different roller blind variants and order types addressed in this process?"*

The roller blind production process at KSA consisted of eight different steps, which were described in the second chapter. Production starts at the sawing workstation, where the profiles of the roller blinds are sawed. Following that, the fabrics are cut at the fabric cutting workstation, and glued to the profiles. Then, if requested, the fabric of the roller blinds is welded. Then, the materials are gathered in the pre-assembly area, and assembled. After the roller blinds are assembled, they are inspected for quality, bubbled, and finally packaged to be shipped.

The different roller blind variants at KSA result in a difference in production times. However, after analyzing the sales data, the weighted average is taken into account with the production times. The different order types have a high impact on the production efficiency, which was analyzed later on in the fourth chapter, however, observing the production process for retail orders and project orders already gave an idea on how project orders are much more efficient, with a smoother flow in production.

Sub-question 2: *"What are the biggest sources of production inefficiencies at KSA according to the findings from the literature, and what is the current production capacity at KSA?"*

The production inefficiencies were identified based on the different categories of waste from Lean Manufacturing. Through observation, timing the processes, and extracting data from the ERP system, the NVA processes were identified, with their percentages (in time). Following that, five sources of production inefficiencies were identified: material handling, employee walking paths, startup inefficiencies, the cart system, and the fabric changeover time.

The current production capacity was also analyzed, because although KSA believes that their current roller blind production capacity is 30.000 roller blinds per year, this number is estimated, and has never been verified. Using the calculated efficiencies associated with project orders, and previous orders' data, the current production capacity of KSA was calculated to be 27.870 roller blinds per year.

Sub-question 3: *"What are the best ways to deal with the identified production inefficiencies?"*

Seven solutions were made based on the identified production inefficiencies. Some of these solutions only focus on certain workstations, while others are for the whole production process, so some solutions were also combined together. The first two solutions are for the sawing and packaging workstations, which change the layout of the workstations with the goal of improving the material handling, employee walking paths, and startup inefficiencies. Then, the third solution is for KSA to use AGVs to push the carts, which optimizes the issue related to the cart system. Solution four then tackles the problem of startup inefficiencies, and it is for KSA to use their already set-up tables within workstations to upscale production. Solutions five to seven then tackle the problem of the fabric changeover time. Solution five is the cheapest one to implement, followed by solution seven, and then six. Solution five includes using a changeover table for the fabrics, while six includes purchasing a new fabric cutting table and an automatic storage unit for the fabrics. Finally, solution seven is to add an extra shift for the fabric cutting workstation.

Sub-question 4: *"What production benefits can be derived from addressing the issues identified in the previous question, and what additional improvements are necessary to reach the target production output of 60k roller blinds per year?"*

The production benefits from the first two solutions is that the steps required per workstation decreased, along with the walking distances by the employees. Naturally, this decreases the time spent at the workstations, which increases the capacity of these workstations. Solution three also decreases the time spent by employees pushing the carts, with a different benefit for each workstation. Then, solution four also increases the output of certain workstations which have tables set-up. The output is different for each workstation, but this solution does not increase the output of the sawing and fabric cutting workstations, since those are constrained by their machines. Solution five then increases the production capacity of the fabric cutting station by 23,58%. The sixth solution increases the production capacity of the fabric cutting station to 70.649 blinds per year. Finally, the seventh solution doubles the production capacity of the fabric cutting station, from 27.870 to 55.740 per year.

Since all solutions (except for the third and fourth solutions) are targeted towards certain workstations, the solutions were combined in order to find a way for the whole production process to be capable of producing 60.000 roller blinds per year. The fourth and fifth solution of implementing the changeover table and hiring an additional employee for the material gathering were combined, which resulted in a yearly output of 34.411. Then, the first, second, fourth, fifth, and seventh solutions of redesigning the sawing and packaging workstations' layouts, hiring extra employees, utilizing the changeover table, and adding a second shift for fabric cutting were all combined, resulting in an output of 64.598 roller blinds per year. Finally, the same combination of solutions was tested, with the addition of the third solution of using AGVs to push the carts. The result was a yearly output of 60.631 roller blinds per year, with the cost of 222.702 euros yearly, and an initial investment of 12.220 euros.

Sub-question 5: *"What are the best fitting recommendations that can be made to KSA based on the results of the previous chapters?"*

KSA should design and produce the fabric changeover table before the end of 2024, which increases their production output to 34.217 roller blinds per year.

Following that, by the end of 2025, assuming that demand has risen to approximately 45.000 roller blinds per year, KSA should start operating a second shift for the fabric cutting table, requiring two new employees to be hired for the fabric cutting workstation. Moreover, they should hire an extra employee for the material gathering workstation. AGVs should also be purchased to push the carts from one workstation to the next. Three AGVs should be purchased before the end of 2025, to push the cart between the material gathering workstation and the assembly workstation, the assembly and quality inspection workstations, and assembly to bubbling. Finally, the packaging workstation should be re-designed based on the second solution in chapter five.

Before 2030, assuming that demand has risen to approximately 60.000 roller blinds per year, KSA should hire four more employees. These employees are for the material gathering, assembly, packaging, and bubbling workstations. Moreover, the sawing workstation should also be re-designed as shown in the first solution in chapter five.

7.2 Limitations

Despite the analysis which was done and the recommendations which were given to KSA in this research, several limitations should be acknowledged. These limitations include time limitations, testing limitations, and scope limitations. The time limitation leads to the testing limitation.

The timeline for this research is 10-weeks, so there is a time constraint, limiting the depth of where this research can go. Because of this time constraint, there is the limitation of testing the proposed solutions and recommendations. As the solutions and recommendations are targeted to be taken within the coming six years, it is not possible to test them. Moreover, some of the solutions could not be tested alone because of their high costs or because of the time constraint. For instance, the efficiency gains from implementing AGVs between workstations were estimated based on ideal conditions, which may not fully capture the complexities of actual implementation. They were also tested based on where the carts would theoretically be, and on their speed, not taking into account outside factors which could slow them down, such as an increased weight in the cart it is pushing.

Regarding the scope limitations, as stated, KSA manufactures two products, the roller blinds and the pleated blinds. The scope of this assignment is to solely upscale production for the roller blinds, not considering the pleated blinds line. Naturally, when KSA expands to the DACH and UK markets, the demand for pleated blinds will also increase, however, there has not been a capacity study done for the pleated line as of yet. Additionally, by limiting the scope of the research, some factors are not considered or they are assumed. For example, the research assumes a relatively stable demand growth and does not account for potential market disruptions or technological changes that could impact the outcome of the research. An assumption of steady demand is made, otherwise the scope of the assignment would be shifted. Moreover, the research did not deeply explore the impact of external factors such as supply chain disruptions, which could affect the implementation of the proposed solutions. Finally, the research's focus on Lean Manufacturing principles and waste reduction may not fully address all aspects of production efficiency, such as energy consumption or environmental sustainability. The emphasis on cost and production output could neglect other factors which Kvadrat could view as critical.

7.3 Future Opportunities

Building on the identified limitations, there are several future opportunities for research.

The first future research opportunity is for a capacity study to be done for the pleated line, similar to this research. This study can be done using Lean Manufacturing principles, but other methodologies could work too.

Moreover, after analyzing the solutions from this research, it is clear that the material gathering workstation is one which needs further improvement, since it required two more employees to reach the target output. For further research, the material gathering workstation should be made more efficient, since having a total of four employees for gathering materials costs 120.000 euros per year.

The third future opportunity for research is the investigation of external factors such as supply chain and economic variability. Developing strategies to mitigate the impact of these externalities on production could make the proposed solutions more realistic. Furthermore, future studies could examine the integration of energy efficiency and environmental sustainability with the Lean Manufacturing framework, or other frameworks, ensuring a more holistic approach to operational improvements, and a better alignment with the future goals of Kvadrat.

The fourth future opportunity for research at KSA is for a proper demand forecast to be made for the upcoming years. With a proper demand forecast, making assumptions about steady demand will not be necessary. It would also benefit the planning at KSA if they have a forecast for the demand.

The final research opportunity which could benefit the production process at KSA immensely is utilizing modularity in production. Since there is a high number of fabric types and roller blind variants, scheduling becomes an issue, because it is very rare for the same fabric to be used in different retail orders. If modularity is utilized at KSA, then optimizing the scheduling process would make the production much more efficient, to utilize the efficiency related to project orders.

7.4 Contribution to Theory & Practice

This research contributes and adds value to both theoretical and practical realms.

Theoretically, it increases the understanding of how Lean Manufacturing principles can be applied to increase production efficiency. By identifying specific inefficiencies and proposing targeted solutions, the research shows how Lean Manufacturing tools can be adapted to be used in real-life situations. The detailed analysis of different solutions and their combinations provides a valuable framework for future research with similar goals or in similar industries.

Practically, the research offers actionable recommendations for KSA to scale up their roller blind production efficiently. The proposed solutions, ranging from immediate changes like the implementation of a fabric changeover table to long-term strategies such as hiring additional employees and redesigning workstations, provide a clear roadmap for KSA to follow.

Furthermore, the research highlights the importance of a phased approach to implementing production improvements, emphasizing short-term, mid-term, and long-term strategies. This approach allows KSA to gradually adapt to changes and mitigate potential risks, ensuring a smoother transition to higher production capacities. The emphasis on cost-effective solutions also aligns with practical constraints faced by KSA, making the recommendations more feasible and attractive.

Overall, this research contributes to both theory and practice by providing a detailed analysis, practical recommendations, and a forward-looking perspective on improving production efficiency, resulting in increasing the production output.

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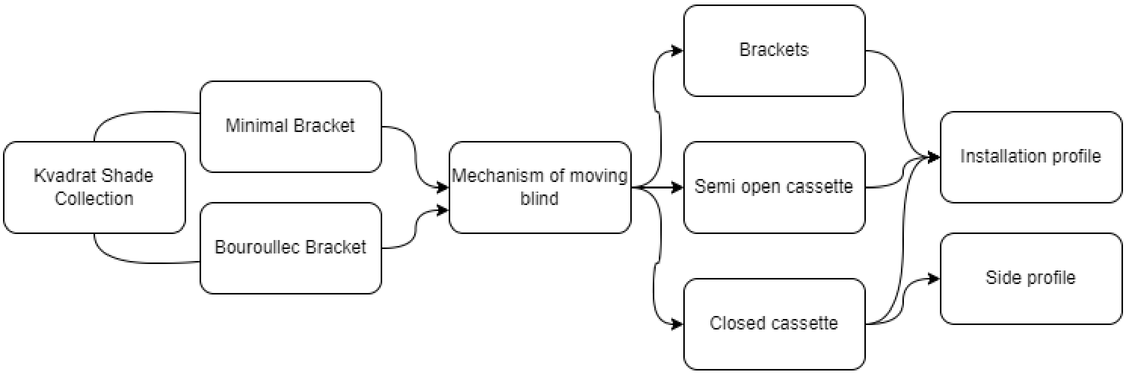
Appendix

Appendix A: Roller Blind Naming



RCKM- is the Minimal Bracket range, while RCK- is the Bouroullec range. Following the "–" are the specifications of the roller blind. The first letter which follows the – is either an S, M, or L, highlighting the frame size of the roller blind. Then, the letter after the frame size is either A, B, or I, highlighting the mechanism of moving the blind. A is for a manual chain, B for motorized, and I is for twin pull. Finally, there is a number which follows the mechanism of moving the blind. The number is either 10, 11, 21, or 31, highlighting the extra options in the roller blind. 10 is only brackets, 11 is brackets with an installation portfolio, 21 is a semi-open cassette, 31 is a closed cassette. Side guides are not represented in the model name, since they are mostly added for functionality purposes as explained in the previous sub-section. Additionally, some roller blind variants include a –I in the end, which indicates that they are two roller blind systems in one.

Appendix B: Roller Blind Variants

Bouroullec		
System	**Type**	**Control**
RCK-SA21	Bouroullec, small, semi-open cassette	Manual
RCK-SB21	Bouroullec, small, semi-open cassette	Motor
RCK-SA31	Bouroullec, small, closed cassette	Manual
RCK-SB31	Bouroullec, small, closed cassette	Motor
RCK-MA10	Bouroullec, medium, brackets	Manual
RCK-MB10	Bouroullec, medium, brackets	Motor
RCK-MI10	Bouroullec, medium, brackets	Twin pull
RCK-MA21	Bourellec, medium, semi-open cassette	Manual
RCK-MB21	Bourellec, medium, semi-open cassette	Motor
RCK-MI21	Bourellec, medium, semi-open cassette	Twin pull
RCK-MA31	Bouroullec, medium, closed cassette	Manual
RCK-MA31-I	Bouroullec, medium, closed cassette, intermediate	Manual
RCK-MB31	Bouroullec, medium, closed cassette	Motor
RCK-MB31-I	Bouroullec, medium, closed cassette, intermediate	Motor
RCK-MI31	Bouroullec, medium, closed cassette	Twin pull

Bouroullec Range

Minimal		
System	**Type**	**Control**

RCKM-SA10	Minimal, small	Manual
RCKM-SA11	Minimal, small, installation	Manual
RCKM-SB10	Minimal, small	Motor
RCKM-SB11	Minimal, small, installation	Motor
RCKM-MA10	Minimal, medium	Manual
RCKM-MA11	Minimal, medium, installation	Manual
RCKM-MA10-I	Minimal, medium, installation, intermediate	Manual
RCKM-MB10	Minimal, medium	Motor
RCKM-MB11	Minimal, medium, installation	Motor
RCKM-MB10-I	Minimal, medium, installation, intermediate	Motor
RCKM-MI10	Minimal, medium	Twin pull
RCKM-MI11	Minimal, medium, installation	Twin pull
RCKM-LA10	Minimal, large	Manual
RCKM-LB10	Minimal, large	Motor

Minimal Range

Appendix C: Roller Blind Production Times

Product	Sawing Time (m)	Fabric Cutting Time (m)	Pocket Welding Time (m)	Gathering Materials Time (m)	Assembly Time (m)	Quality Check Time (m)	Bubbling Time (m)	Packaging Time (m)	Total Time (m)
RCK-SA21	6,64	6,59	3,00	10,00	6,22	6,95	4,32	10,85	54,56
RCK-SB21	6,64	6,50	3,00	3,00	6,21	11,46	2,31	3,83	42,94
RCK-SA31	6,96	6,22	3,00	3,83	6,20	4,27	2,29	3,79	36,56
RCK-SB31	6,81	6,46	3,00	3,00	6,32	4,86	2,74	3,97	37,16
RCK-MA10	2,18	8,07	3,00	2,60	3,24	6,40	3,90	7,48	36,86
RCK-MB10	7,71	7,00	3,00	10,00	6,33	6,61	2,46	11,29	54,41
RCK-MI10	7,69	6,45	3,00	3,00	6,29	4,44	2,42	4,16	37,45
RCK-MA21	7,65	6,62	3,00	10,00	6,23	5,57	2,34	10,91	52,32
RCK-MB21	4,53	8,40	3,00	11,60	9,09	7,38	4,01	7,82	55,83
RCK-MI21	5,56	7,62	3,00	11,07	8,12	5,82	3,44	8,81	53,45
RCK-MA31	12,07	8,17	3,00	21,40	9,05	7,07	3,97	7,70	72,42
RCK-MA31-I	38,09	30,01	6,00	42,80	29,99	26,32	14,07	30,93	218,22
RCK-MB31	7,68	6,75	3,00	3,00	6,28	5,67	2,40	4,09	38,86
RCK-MB31-I	28,72	20,21	6,00	42,80	21,95	14,67	8,73	17,75	160,83
RCK-MI31	11,24	8,65	3,00	11,47	8,83	7,39	2,95	7,72	61,24

Bouroullec

Product	Sawing Time (m)	Fabric Cutting Time (m)	Pocket Welding Time (m)	Gathering Materials Time (m)	Assembly Time (m)	Quality Check Time (m)	Bubbling Time (m)	Packaging Time (m)	Total Time (m)

RCKM-SA10	7,53	6,25	3,00	10,00	6,04	4,15	2,09	10,17	49,24
RCKM-SA11	7,46	5,80	3,00	10,00	5,95	2,99	1,96	9,78	46,94
RCKM-SB10	7,60	6,18	3,00	10,00	6,16	3,03	2,24	10,63	48,85
RCKM-SB11	7,54	6,07	3,00	10,00	6,06	3,79	2,11	10,23	48,81
RCKM-MA10	7,73	6,98	3,00	10,00	6,36	5,80	2,51	11,43	53,81
RCKM-MA11	7,60	6,36	3,00	10,00	6,15	4,70	2,24	10,61	50,66
RCKM-MA10-I	15,31	12,74	6,00	20,00	12,47	7,60	4,69	21,87	100,67
RCKM-MB10	7,68	6,87	3,00	10,00	6,28	6,52	2,41	11,12	53,88
RCKM-MB11	7,75	7,16	3,00	10,00	6,38	6,05	2,54	11,51	54,39
RCKM-MB10-I	16,26	15,99	6,00	20,00	13,90	12,97	6,61	27,61	119,35
RCKM-MI10	7,63	6,69	3,00	10,00	6,21	6,42	2,30	10,81	53,06
RCKM-MI11	7,60	6,17	3,00	10,00	6,15	3,05	2,22	10,57	48,76
RCKM-LA10	7,70	7,05	3,00	10,00	6,30	6,10	2,43	11,20	53,79
RCKM-LB10	7,71	6,67	3,00	10,00	6,33	5,37	2,47	11,32	52,87

Minimal Bracket

Appendix D: Roller Blind Replacers

Verosol	Kvadrat Shade
System	**Replacer**
QS60.0	RCKM-S*.10
QS60.4	RCKM-S*.10
QS60.5	RCKM-S*.10
QS61.0	RCKM-S*.11
QS61.4	RCKM-S*.11
QS61.5	RCKM-S*.11
QS62.0	RCK-S*.21 / RCK-S*.31
QS62.4	RCK-S*.21 / RCK-S*.31
QS62.5	RCK-S*.21 / RCK-S*.31
QS80.0	RCKM-M*.10
QS80.4	RCKM-M*.10
QS80.5	RCKM-M*.10
QS81.0	RCKM-M*.11
QS81.4	RCKM-M*.11
QS81.5	RCKM-M*.11
QS82.0	RCK-M*.21 / RCK-M*.31
QS82.4	RCK-M*.21 / RCK-M*.31
QS82.5	RCK-M*.21 / RCK-M*.31
QS83.0	RCK-M*.21 / RCK-M*.31
QS83.4	RCK-M*.21 / RCK-M*.31
QS84.0	RCK-M*.21 / RCK-M*.31
QS84.4	RCK-M*.21 / RCK-M*.31
QS22.0	RCK-S*.31 / RCK-M*.31
QS22.4	RCK-S*.31 / RCK-M*.31
QS22.5	RCK-S*.31 / RCK-M*.31
R32.0	RCK-S*.21 / RCK-S*.31

R32.4	RCK-S*.21 / RCK-S*.31
R33.0	RCK-S*.21 / RCK-S*.31
R38.0	RCKM-L*.10
R38.4	RCKM-L*.10

Appendix E: Project Order Efficiency

SAWING
BOM
Gather Materials
Input measurements
Sawing
Stickers
Moving cart
Putting logo
Picking up new cart
Sawn parts on cart
Materials back

Fabric Cutting
Changing roll
Inputting measurement
Cutting
Picking up cut fabric
Rolling tube
Moving cart
Sawn parts from cart
Throwing away extra fabric
Walking with machine to lift roll
Maching pulling fabric
Moving fabric to roll
Putting rolled blind on cart

Welding
Welding (with machine)

Pre-assembly
Gathering materials
Searching
Moving cart

Assembly
Walking to cart
Reading BOM

Assembling

Inspection
Walking to cart
Changing brackets
Putting rollo on brackets
Inspection
Fixing something
Putting chain blocker

Bubbling
Walking to cart
Bubbling

Packaging
Scanning BOM
Grabbing from cart
Looking for packaging
Making the box
Packaging
Making bubble puff
Wrapping box
Putting box on cart
Stickers on box + printing them