Saving Space and Improving Efficiency in the Assembly Department

BSc - Industrial Engineering and Management

Author:
M.H.B. Derwig (Max)
27/09/2022

University Supervisors
MSc M. Koot (Martijn)
Dr.Ir. J.M.J. Schutten (Marco)

Company Supervisors
J. Pierik (Joris)
T. Geurkink

Preface

Dear reader,

This is the Bachelor thesis 'Saving Space and Improving Efficiency in the Assembly Department.' This research is conducted at company Y between April 2022 and August 2022.

First, I would like to thank company Y for providing this research assignment. Furthermore, special thanks go to my supervisors, Joris Pierik and Tycho Geurkink, for their support, guidance, and help.

Next, I want to thank my University supervisor Martijn Koot for his guidance, positivism, and input. Our meetings were helpful and boosted me to perform better. Furthermore, I want to thank Marco Schutten as my second supervisor. Especially for the critical feedback he provided during the last few weeks raised the quality of my research.

Furthermore, I want to thank my friends and buddies Stef and Koen for providing feedback and for the endless meetings to discuss our difficulties.

Finally, thank my family and friends for their support and optimism.

I hope you enjoy reading my thesis!

Max Derwig

Enschede, September 2022

List of Figures

List of Tables

List of Abbreviations

ERP	Enterprise Resource Planning
MPSM	Managerial Problem-Solving Method
VLM	Vertical Lift Module
HMLV	High-Mix Low-Volume
WIP	Work-In-Progress
SPS	Set Part Supply (a kitting process)

Contents

Management Summary

This research is conducted at company Y. It is the mission of company Y to provide the manufacturing industry with high-quality sheet metal and assemblies. For example, cabinets, housings, frames, machine covers, and complete (electro) mechanical modules.

Motivation

The focus of this research is on the assembly department of company Y. Here parts come together to be assembled into one of the 8,000 products company Y produces. Due to the company's growth in recent years, the assembly department is at risk of growing out of its current location and becoming the bottleneck of the facility. Therefore, this research focuses on saving space in the assembly department while increasing efficiency.

Research Question

Currently, company Y moves too many pallets to the assembly department. Therefore, the main research question of this thesis is: *"How can the packaging and picking operations of company Y be adjusted to save space and increase efficiency in the assembly department?"*

This research addresses the packaging and picking operations to reduce the number of box pallets in the assembly department. Additionally, the solution has to increase efficiency. This increase in efficiency reduces movement between the warehouse and the assembly location.

Methods

This research uses the Managerial Problem Solving Method (MPSM). First, observations and conversations result in a better understanding of the process and the problem. These observations and conversations result in a performance analysis of the assembly department. This performance analysis identifies two bottlenecks: too many box pallets in the assembly department and too many movements from the warehouse to the assembly department.

The foundation of this research is the two bottlenecks and the literature research. Furthermore, the literature research helps to identify possible solutions. Therefore, a suitable strategy was found based on the performance analysis and the literature research. This strategy is a kitting strategy and is used to supply the assembly location. Additionally, the kitting strategy reduces required space, ensures that all parts arrive at the assembly location simultaneously, and reduces movement during picking operations.

The MPSM creates multiple solutions in terms of picking, production, and packaging. These solutions incorporate a new picking strategy, a new packaging method, and a new production schedule. The best suitable and performing solution is chosen to solve the problem by evaluating and comparing these alternative solutions.

Results

The combination between the new strategy and the kitting container results in less movement from the warehouse to the assembly department. Currently, parts are collected from the warehouse using a forklift; with the new strategy, parts are picked directly from the warehouse into the newly designed kitting container. Additionally, this reduces the number of movements within the assembly department. Another benefit of the new situation is the reduced number of box pallets in the assembly department. In addition, the kitting container stores parts more efficiently, requiring less space.

Recommendation

We recommend that company Y implements this new kitting strategy which includes: picking directly from the warehouse into the newly designed kitting container. By doing so, the assembly department becomes more efficient in terms of movement from the warehouse to the assembly department. Additionally, the solution saves space in the assembly department due to the new kitting containers. Furthermore, after implementing the solution, it is advisable to evaluate it to ensure it has the desired outcome.

1 Introduction

This chapter consists of three subsections. Section 1.1 introduces the company, Section 1.2 identifies the core problem, and Section 1.3 discusses the problem-solving approach.

1.1 Company Y

Company Y is a supplier of metal sheets and assemblies. Company Y has expertise in sheet metal working, welding, powder coating, assembly, and cleanroom products. Company Y produces over 8,000 different products in over 20,000 orders.

It is the mission of company Y to provide the manufacturing industry with high-quality sheet metal and assemblies. These assemblies consist of cabinets, housings, frames, machine covers, and complete (electro) mechanical modules.

Over the last few years, company Y has grown substantially. Figure 1 shows the revenue for the last five years and the expectation for 2022. Especially 2021 has been a good year for company Y with an increase in revenue of 32% compared to 2020. Due to this growth, company Y has faced problems with production capacity throughout its facility. Therefore, company Y has been innovating and investing in multiple departments to increase production capacity. Recently company Y purchased multiple new machines, which increased the production capacity at the beginning of the process. However, these investments moved the bottleneck further down the process to the assembly department. Therefore, the assembly department is at risk of growing out of its current location. Section 1.2 further elaborates on the problem company Y faces in the assembly department.

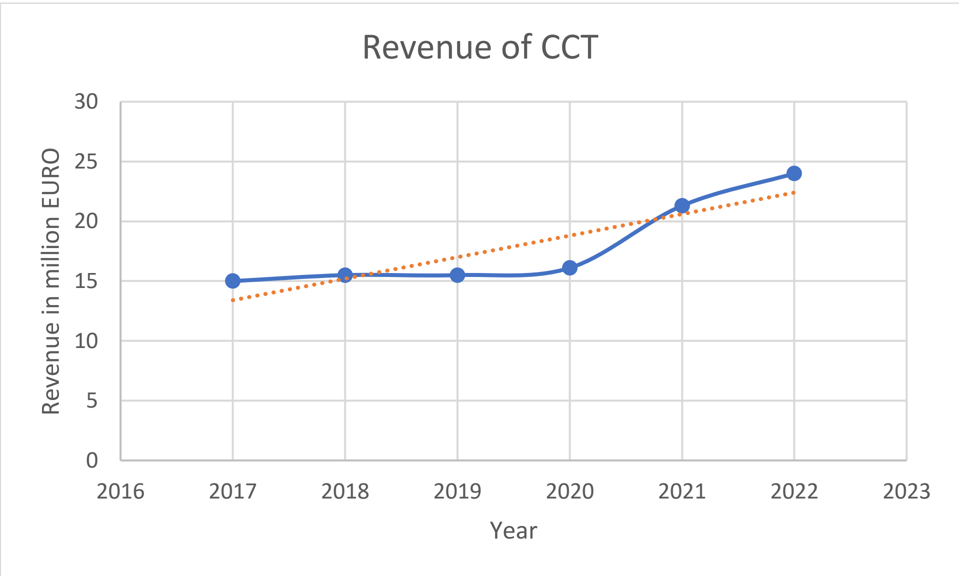


Figure 1: Revenue History for company Y

1.2 Problem Identification

1.2.1 Action Problem

Due to the growth of company Y, the assembly department is now at risk of growing out of its current location. There is not enough room in the assembly department's hall (1160 m^2). As a result, the processes in the department become less efficient since the crowdedness results in longer walking distances and increased time spent on finding parts.

To overcome this problem, company Y has been innovating in this department; the most recent innovation is the investment in two LEAN lifts. These lifts enable a vertical way of storing parts, saving floor space in the department. However, the workplace remains crowded due to parts or products that remain on the work floor. Furthermore, the cleanroom[1] will be renewed and enlarged from 48 m^2 to 192 m^2 within a few months. However, this enlargement leaves even less room for assembly. Therefore, company Y wants to redesign and optimize its assembly department with the new cleanroom in mind to make the workplace less crowded and increase productivity.

This research continues on the master thesis of Samson Loboka (Loboka, 2022). He did his master's thesis for Industrial Engineering and Management at company Y about improving the efficiency of the assembly department. His research focuses on four topics; layout, picking, storing, and assembling. Loboka's research increased the flow of materials through the assembly department; this research will focus on saving space and improving overall efficiency. Therefore, this thesis continues Loboka's work and uses some of his work as a foundation. Loboka's research also provided a research direction for this thesis. His research suggested that a kitting solution might be beneficial for company Y to save space in the assembly department and improve the picking operations.

1.2.2 Problem Cluster & Motivation of Core Problem

The action problem company Y provided is the crowded workplace. The causal relations to this action problem were determined by thinking backward and observing the assembly department, as shown in the problem cluster (Figure 2). These actions result in four potential core problems. Identifying the relations between the problems was done by using the problem identification by Heerkens & van Winden (2017).

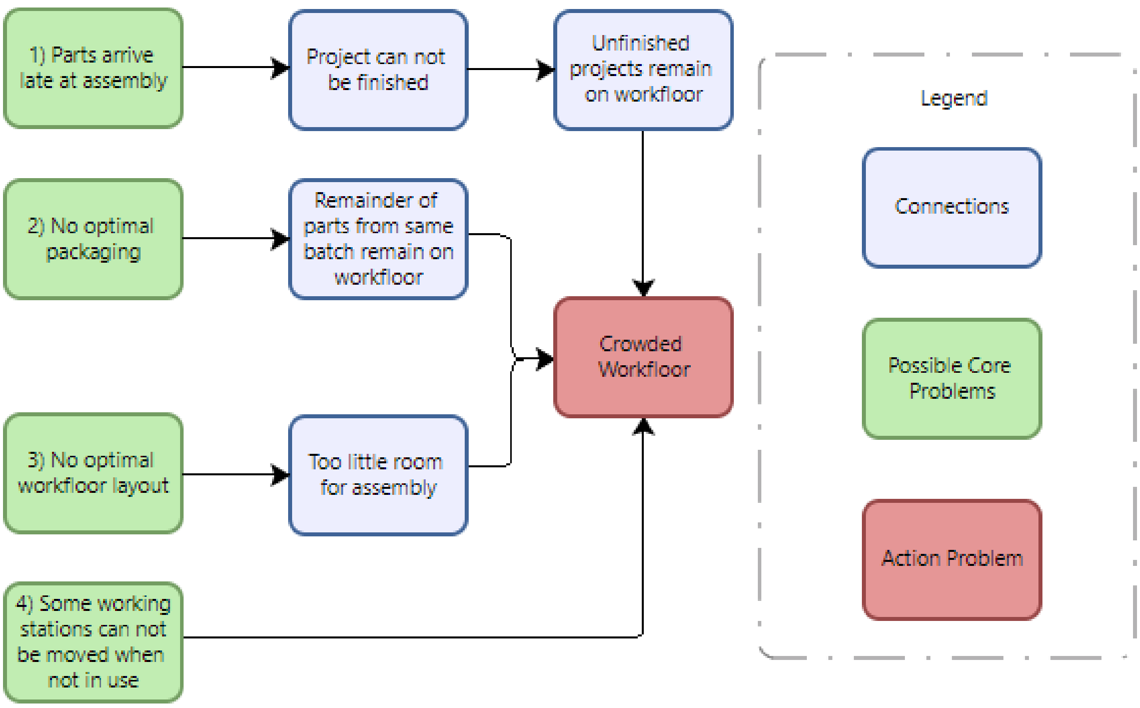


Figure 2: Problem Cluster Showing the Relations Between Problems

[1] A cleanroom is a room where parts or products can be assembled or packaged in a low dust environment.

The first possible core problem is that parts arrive late at assembly; therefore, the projects cannot be finished and remain in the workplace. These late parts are both from external suppliers and internal production. The late parts from external suppliers are outside the influence of company Y since they are ordered on time but delivered late due to problems at the suppliers. The late parts from internal production are within the influence of company Y.

The second possible core problem is that too many parts are moved to the assembly department when the assembly starts. Currently, company Y packages internally produced parts in batches. However, these batches are not the same size as the required size at the assembly department. For instance, assembling a product requires two doors. However, company Y produces and packages these doors in batches of eight. Therefore, six doors remain in the assembly department after assembling the product.

The third possible core problem is no optimal workplace layout; company Y assembles multiple projects simultaneously. Company Y assembles some of these projects continuously while assembling other projects in batches. Continuous means that when an assembly finishes, the next one starts right away. Production in batches means the assembly of certain products occurs once every few weeks in a higher volume. The continuous projects have a designated area in the department, but there is no clear structure for where to store parts used in the assembly. The assembly worker places the necessary parts near the assembly location without structure. Therefore, the lack of an optimal layout and structure results in a long time spent fetching parts. Furthermore, the cleanroom at the assembly department will be moved and enlarged later this year, resulting in even less space on the work floor. Therefore a new layout of the department is imperative.

The fourth possible core problem is that moving some working stations and storage racks is impossible. Some working stations have wheels and are moveable when not in use. However, this does not apply to all working stations. Reasons for this lack in moveability vary per working station. In some cases, the tables or equipment do not have wheels. In other cases, the equipment is too large to be moved. These cases result in space loss when a specific product is not under production since the racks and working stations cannot be put aside and take up valuable workspace.

All possible core problems relate to the action problem of a crowded workplace, which results in a limited capacity to execute activities. The first core problem is outside the scope of the assembly department; this problem occurs on the production side of company Y and is thus out of control for the assembly department. By redesigning the layout of the assembly department, the efficiency would increase. However, this would not necessarily save space. Redesigning a facility layout increases efficiency and productivity. Sometimes redesigning the layout of a facility saves floor space, but this is not always the case. This reasoning eliminates the third potential core problem as core problem. By solving the fourth core problem, the workstations would become moveable, thus saving space in the assembly department. However, the movement of these workstations is waste according to LEAN theory and therefore reduces the efficiency of the assembly department (Theisens & Hampsink, 2017).

By solving core problem two, the efficiency is increased since the number of movements to pick parts will be reduced due to the new design of the packaging and new strategy. Additionally, by solving this core problem, space is saved in the assembly department since only the parts required would be moved to the assembly department. Furthermore, fewer box pallets are received by only sending the desired parts to the assembly department, thus saving space. Therefore, the core problem for this research is core problem two. The solution for this problem results in increased efficiency and saves space in the assembly department.

1.2.3 Norm & Reality

Due to the crowdedness of the assembly department, company Y wants to make the work floor less crowded and, by doing so, ensure a smoother flow of materials through the department. In the past, the assembly department had more than enough room to store everything, but with rapid growth in the past few years, little has changed about the department's working methods. The reality is that most employees still think they have enough room to leave everything on the work floor. Thus, there is no system or strategy to move unwanted materials or projects elsewhere. Instead, the norm is that everything that is not directly needed is moved or does not reach the department until it is needed.

A norm makes it possible to solve the problem; without a norm, it is impossible to determine when a problem is solved. Company Y sets this norm as more free space and more efficient flow. However, to ensure the achievability of the goal, it is necessary to make the norm measurable. Therefore, this research introduces two variables that enable the measurement of the problem.

The first variable is the number of box pallets on the work floor. Observations determined that, on average, there are 80 box pallets present in the assembly department on any given day. These 80 box pallets take up 76.8 m^2 of the total 1160 m^2 that is available in the assembly department. Not all these box pallets are in use when present. The solution's effectiveness, in terms of saved space, compares the number of box pallets before and after implementation.

The second variable this research uses is the number of movements. The second goal of this research is to increase the efficiency of the assembly department. Increasing the efficiency is done by looking at movement on the work floor. According to LEAN theory, unnecessary movement is a form of waste. Therefore, reducing movement is considered an increase in efficiency. This research divides movement into two sections, the movement toward the assembly department and the movement to pick parts. These will be measured and compared to ensure the solution reduces movement.

1.3 Problem Solving Approach

1.3.1 Core Problem Definition

As defined in Section 1.2.2, the core problem is the lack of an optimal packaging method, which means there is a possibility to improve the transportation of parts to the assembly department. Redesigning the packaging saves space since this reduces the number of box pallets that are moved to the department. Furthermore, the new packaging method also increases efficiency since it reduces the time spent fetching parts. Moreover, the new method reduces the number of movements toward the assembly department.

The central perspective this research uses is the LEAN theory. The LEAN theory uses the reduction of waste to improve processes and operations. For example, movement is a waste; therefore, reducing the movement towards the assembly department is considered a LEAN improvement.

This research uses space and time variables discussed in Section 1.2.3 to solve the problem. The following section discusses the research structure by introducing a research question and sub-questions.

1.3.2 Structure

The main goal of this research is to save space and improve efficiency in the assembly department. Therefore, the main research question of this thesis is:

How can the packaging and picking operations of company Y be adjusted to save space and increase efficiency in the assembly department?

The reduction of box pallets in the assembly department achieves the goal of saving space. In addition, two independent improvements achieve the goal of increasing efficiency. First, the number of movements towards the assembly department reduces. Secondly, the time spent picking parts reduces since assembly workers have fewer box pallets to go through before finding the desired part. By achieving these goals solves the problem.

Chapter 2 discusses the current situation to explain the processes. This research includes a performance analysis to identify bottlenecks. Chapter 2 answers the following three sub-questions:

- *What is the current flow of materials through the facility?*
- *How does the process currently perform regarding movement and the number of pallets in the department?*
- *What are the bottlenecks in the current process in terms of used space and efficient operations?*

Chapter 3 reviews literature to gain knowledge and creates a theoretical framework. The solutions use this theoretical framework as a foundation. In combination with the bottlenecks, it discusses multiple solutions to the problem. Chapter 3 answers the following sub-questions:

- *What possible solutions are available in LEAN theory, considering the goals of saving space and increasing efficiency?*
- *What are the benefits and limitations of these possible solutions?*
- *What to consider when implementing a solution regarding additional modifications to the existing process?*
- *What possible solution provides the best promise in terms of achieving the goals of this research?*

Chapter 4 elaborates on the chosen solution and creates multiple alternatives. The sub-questions for Chapter 4 are:

- *What are possible picking solutions?*
- *What are possible production solutions?*
- *What are possible packaging solutions?*
- *What can be possible combinations between the three independent solutions?*

Chapter 5 compares the possible solutions from Chapter 4. This comparison results in a chosen solution to solve the problem. Additionally, this chapter includes an implementation plan. The solution will be chosen based on the following two sub-questions:

- *What criteria to consider?*
- *What solution saves the most space?*
- *What solution increases efficiency the most?*
- *How can company Y implement the chosen kitting solution?*
- *How can company Y validate that after implementation, the solution solved the problem?*

Finally, Chapter 6 contains a conclusion and recommendation.

1.3.3 Deliverables

The intended deliverables show what this study provides to the company. These deliverables are listed below with a short explanation.

- New packaging strategy: a new way to package parts in kits that reduces movement and decreases the amount of space used in the assembly department.
- New packaging container: This research will evaluate alternative packaging containers to determine which alternative saves the most space and increases efficiency.
- Implementation plan: The plan includes a blueprint to implement the chosen solution.

2 Current Situation

This chapter discusses the current situation. The goal of this chapter is to create a good understanding of the current situation, including layout, flow of material, storage, picking and assembly. First, Section 2.1 explains the current situation for the entire facility. Then, Section 2.2 describes the assembly department. Next, Section 2.3 analyses the performance of the assembly department. Finally, Section 2.4 concludes this chapter by identifying the bottlenecks.

2.1 Facility Description

2.1.1 Product Variety

Company Y produces a variety of over 8000 different products in a high-mix-low-volume setting (HMLV). HMLV means that company Y produces products to order and not in large batches since there is too much variety. Products can vary from small sheet metal products to large complex assemblies. These assemblies consist of cabinets, housings, frames, machine covers, and complete (electro) mechanical modules.

2.1.2 Facility Layout

This section discusses the facility's layout and introduces the 6 production departments. These are cutting, bending, manual work, welding, painting, and assembly. Next, the layout of the assembly department will be explained in more detail since this thesis focuses on the assembly department.

2.1.2.1 Cutting

In the cutting department, a laser cuts the sheet metal. Additionally, some machines can punch a hole or tap a screw thread in the sheet metal. Two machines perform these processes; one can only cut, and the other can cut, punch, and tap. The sheet metal is fed to these machines by an automated sheet metal warehouse. This warehouse has two shelf racks and in between is a robot arm. This arm can move between the two shelf racks to pick sheet metal and directly feed it to the machines where the processing of the metal begins.

2.1.2.2 Bending

Almost all the parts from the cutting machine move to the bending department. However, some parts do not require bends and move to the warehouse. In the bending department, a die-bending machine bends the sheet metal, meaning each bent has a specific die that must be placed in the machine. In addition, two automated bending machines are connected to the automated sheet metal warehouse, as described in Section 2.1.1. These automated bending machines usually bent more extensive components with high volume batches. Additionally, these bending machines can run through the night. Additionally, company Y uses manual bending machines for more complex bending processes and smaller articles.

2.1.2.3 Manual Work

The manual work department performs processes that are impossible to execute automatically; these include spot welding, tapping, and drilling.

2.1.2.4 Welding

The welding department is responsible for welding together frames and boxes. Company Y produces one product in substantial batch sizes. This product has a specialized automated welding machine. Other welding processes are done manually by employees. They often use a mold to ensure each part is orientated correctly and reduce errors in the welding process.

2.1.2.5 Painting

The paint shop uses powder coating to paint parts or articles; this process is rather extensive. First, the article needs to be cleaned thoroughly in multiple baths. Next, blowers remove any remaining water. If necessary, an employee removes any remaining water manually. Then the articles move through the coating cabin, where either a robotic arm or an employee coats the articles. Next, the articles need to be heated to adhere to the coating. Finally, the articles are inspected and packaged for transportation to other departments or clients.

2.1.2.6 Pickling

The pickling process uses acid to treat metals and ensure a higher surface quality (Regel-Rosocka, 2010). However, the pickling process is not yet active since company Y only recently started construction on the pickling facility.

2.1.2.7 Assembly

The assembly department is next to three other departments within the facility, as seen in Figure 3. These departments are pickling, warehouse and expedition. The department that pickles metals for company Y is located next to the assembly department because it is often the last step in the process before finishing the part and ready for assembly. The warehouse is next to the assembly department because assembly workers often pick from the warehouse. The third department is expedition, where finished products are packaged and sent to the client. All these departments are logically next to the assembly department due to the flow of parts or products. By placing them close to each other, the transportation times are kept to a minimum, thus being more efficient.

Figure 3: Facility Layout Map company Y (The arrows show the flow of articles through the facility)

2.1.3 Flow through Facility

An ERP system called ISAH monitors the flow of materials and products through the facility. Within ISAH, every article or product has an article number. Both internally produced parts, assemblies, and externally ordered parts have an article number. Furthermore, each article has a workbook that goes with the article through the facility. The workbook contains relevant information about the part, such as technical drawings and product routing. The routing is shown in codes and visualizes which departments an article must visit before completion. The routing also shows what processes the article needs within that department. Figure 3: Facility Layout Map company Y (The arrows show the flow of articles through the facility) displays the flow of articles through the facility.

Upon finishing the parts, they are booked into stock. Once all parts for an assembly are in stock, the assembly order is ready to start. The ERP system visualizes the status of the orders on dashboards throughout the facility. There are three status categories: launchable, not launchable, and in progress.

When an order is launchable, it means that the order is ready to be started. Thus all the parts are present and ready within the facility. Not launchable means the order is still missing some parts. Therefore it cannot be started. When an order is in progress, it has already started. Employees work the launchable list from top to bottom. So every time an employee finishes an order, the employee continues with the job on top of the launchable list.

ISAH structures the launchable list based on the delivery date to the customer. So the product that needs to be delivered first is produced first. However, there is an exception in terms of priority orders. Sometimes an order gets priority because it is a rush order or because it has been returned to company Y because it arrived damaged at the customer. ISAH gives these orders a different color and places them on top of the launchable list. Thus receiving priority and produced before other orders.

Figure 4 shows an order's routes through the facility along the different departments. This figure visualizes that the flow of orders can be rather complex based on the requirements of the product.

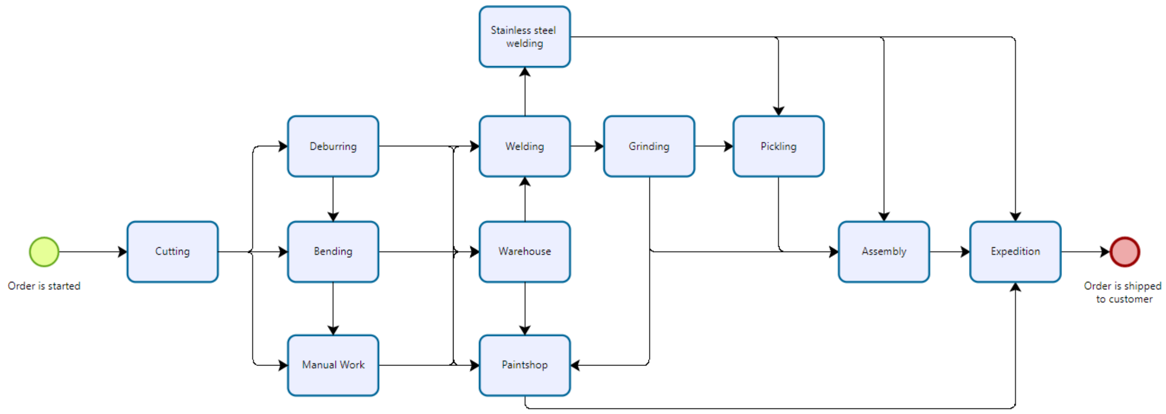


Figure 4: Possible Flow for Orders Through the Facility

2.2 Assembly Department

This section discusses the current situation of the assembly department. Topics include layout, the flow of material, storage, and picking.

2.2.1 Layout

The assembly department is a hall of 1160 m^2. This hall includes a cleanroom where parts or products can be assembled or packaged in a low dust environment. This room currently occupies 48 m^2. However, a larger cleanroom will be installed at the end of this year, covering 192 m^2. Thus the total surface area will be reduced by 144 m^2, leaving 1016 m^2 for regular assembly.

Currently, the assembly department consists of stationary multiple working stations. Each working station has specified equipment, shelves, and parts to assemble specific products. Furthermore, two Vertical Lift Modules (VLMs) are present to store small parts for assembly. The current layout categorizes as a functional layout. The functional layout groups specific resources[2] together (Slack et al., 2016). These groups of resources divide the hall into sections. Each section has specified tools, racks, or other forms of equipment that come with assembling one or multiple products. However, some resources cannot be put in these sections since they must be accessible to all. These resources include the VLMs and shelf racks. Company Y does not locate these resources within specific sections since every section needs access to these resources.

Figure 5 visualizes the current layout of the assembly department. Appendix A provides a more detailed visualization of the current situation. Furthermore, Appendix B shows the new situation with the enlarged cleanroom. Appendix C contains pictures of the assembly department, to visualize the current situation.

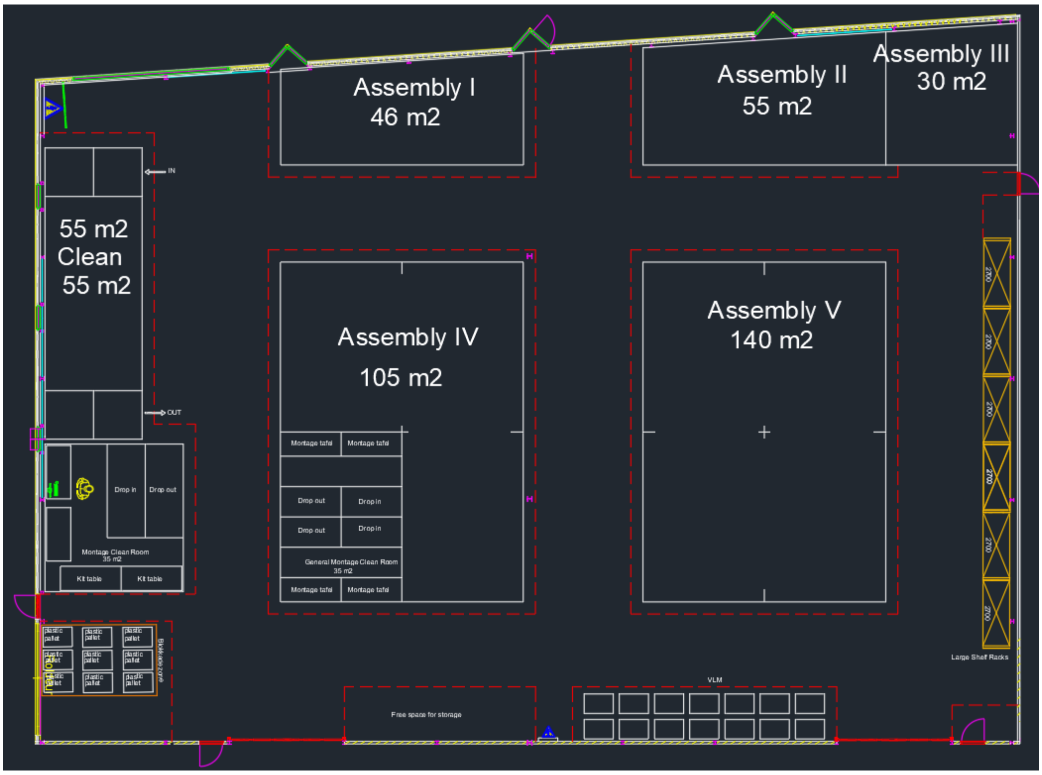


Figure 5: Current Layout of the Assembly Department

[2] e.g. tools, storage facilities, and workplaces

2.2.2 The flow of Materials through the Assembly Department

The assembly department is the place in the facility where multiple parts come together and get combined into the final product. The large variety in assemblies and the number of parts that come with assembling a product make the flow of materials at the assembly department complex. Additionally, the current layout of the assembly department, the functional layout, has the disadvantage that the flow of articles becomes more complex and more difficult to control (Slack et al., 2016).

Articles can enter the assembly department in different ways. They either come from the warehouse, another department, or external suppliers. When articles enter the assembly department, employees move the parts to their designated locations. This designated location can be the assembly location, large shelf racks, small shelf racks, or the VLM. Upon finishing the assembly, the article can be moved to several locations depending on further operations. The flow chart in Figure 6 visualizes the flow of materials.

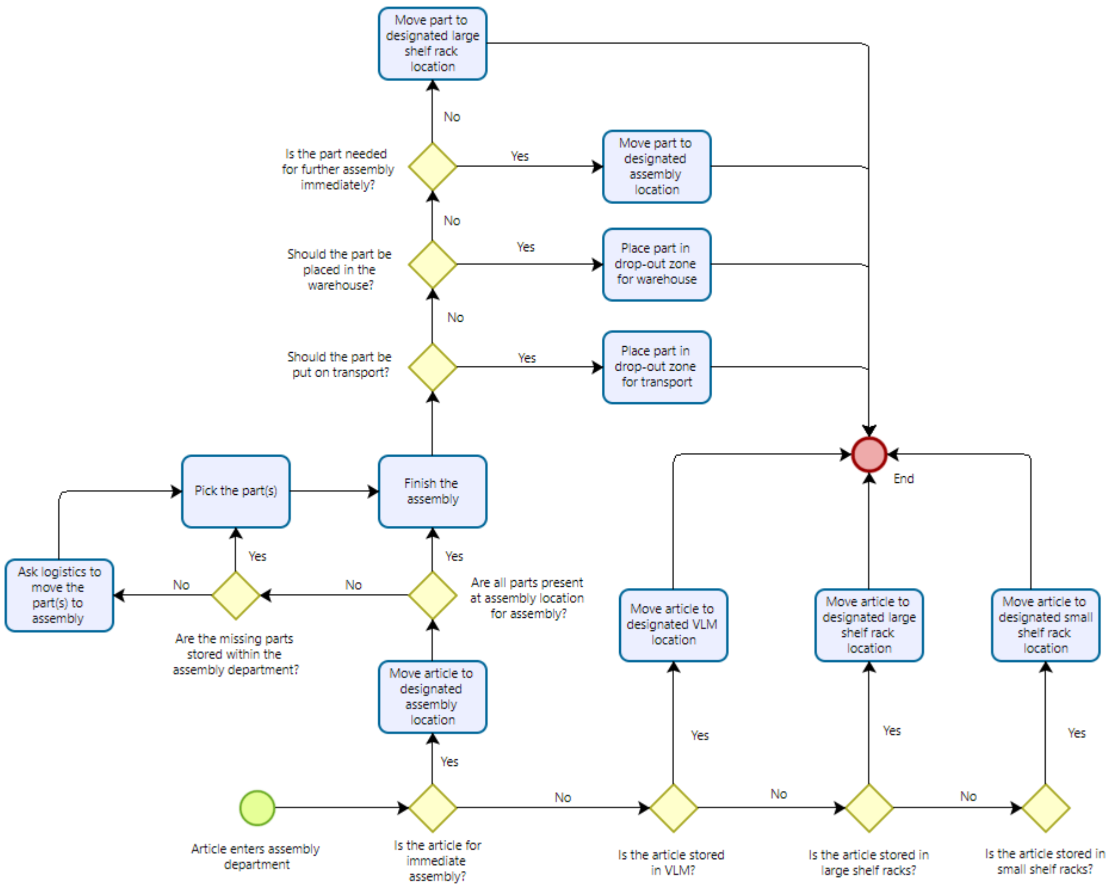


Figure 6: Flowchart for Flow of Materials in the Assembly Department

2.2.3 Storage Assembly Department

There are three storage locations within the assembly department where parts can be stored; the large shelf racks, small shelf racks, and the VLM. All these locations have a location number. So when articles enter the department, an assembly worker unpacks these articles and places them at their designated location.

2.2.3.1 Large Shelf Racks

Company Y uses the large shelf racks to store articles too large for small shelf racks or the VLM. Therefore, large shelf racks primarily store large tubes, packaging materials, and additional stock in box pallets. Additionally, the large shelf rack stores products on which assembly has already started but still misses parts.

2.2.3.2 Small Shelf Racks

Small shelf racks store mostly bolts, screws, and nuts. Company Y places these small shelf racks near every assembly location with designated parts for the assemblies that happen at that location. Therefore, multiple small shelf racks are present since assembly workers use the parts that the small shelf racks store for all assembly processes.

2.2.3.3 Vertical Lift Module

The VLM stores medium-sized parts, ranging from small metal sheets to rubbers or foam. They are stored in the VLM based on article number and combined on the same level with the necessary parts for the same assembly.

2.2.4 Picking Assembly Department

Company Y uses a picker-to-goods-to-order strategy in the assembly department (Richards & Gwynne, 2014). Such a strategy means that the picker, in this case also the assembly worker, picks parts for one order at a time and does this by walking to the parts within the assembly department. These parts can be stored in multiple locations, as discussed in Section 2.3.

The picker brings the parts to the assembly location. Parts stored in the VLMs or shelf racks in the department need to be collected by assembly workers. A logistics employee is notified to collect the required parts if these parts are stored in the warehouse. The logistics employee collects the pallets and brings them to the drop-in zone at the assembly department. From there, an assembly worker must collect the pallets and bring them to the assembly location. The number of box pallets for one assembly can vary from two to fourteen. At the assembly location, all parts come together to create the product. Some orders have a designated assembly location because company Y produces these orders on regular bases. Around this area are the tools and parts that come with assembling the product.

2.3 Performance of the Assembly Department

This section measures and analysis the performance of the assembly department by using the variables from Section 1.2.3. These variables are space and number of movements.

2.3.1 Space

One of the main objectives of this research is to save space in the assembly department. The total surface area available at the assembly department is 1160 m^2. Table 1 shows what objects are present, how much space each object occupies, the quantity in which the object is present in the department, and finally, the total surface area used by these objects. Except for the pallets, all the objects have a fixed quantity in the department. The quantity of the pallets is an average measured over one week.

Object	Surface area (m^2)	Quantity of this object	Total (m^2)
Clean Room	48	1	48 (192)[3]
VLM	6	2	12
Large Shelf Racks	4.5	6	27
Medium Shelf Racks	3	12	36
Small Shelf Racks	1	17	17
Working Table	2	15	30
Small Working Table	1	4	4
Office Table	2	2	4
Pallets	0.96	80	76.8
Orange Pallet Tables	1.2	30	36
Trolley's	1	5	5

Table 1: Objects and Surface Area at Assembly Department

Table 1 shows that the pallets take up most of the space in the assembly department. Moreover, the 80 pallets present at the assembly department is an average. For example, when company Y assembles a cabinet for customer X, the number of pallets can increase by 14 since there are 14 pallets needed to assemble this specific product for customer X. These 14 pallets do not only contain the exact amount of parts required for the assembly. They contain as many parts as that fit in the box pallet. When the assembly process finishes, and there are still parts in the box pallet, they remain on the work floor until the next assembly order for customer X starts. These remaining parts take up valuable workspace.

Removing the other objects to save space in the assembly department is impossible since these objects are essential to execute the operations. Some objects were made moveable by putting them on wheels, so they can be put aside when they are not in use. However, according to the LEAN method, unnecessary movement is a waste. Therefore, the movement of these objects is a waste which reduces efficiency, leaving only the pallets as a means to save space. This conclusion concurs with the core problem.

[3] The clean room will be enlarged by the end of 2022 from 48 m^2 to 192 m^2

2.3.2 Movement

The LEAN theory states that unnecessary movement is a form of waste. Thus reducing movement results in an improvement in efficiency. For example, assembly workers must pick parts from several storage locations before assembly can begin, as discussed in Section 2.2.3. Furthermore, parts need to be picked from the warehouse by a logistics worker on a forklift. These picking operations require movement from the picker to the storage location and from there to the assembly location. Figure 7 visualizes these movements.

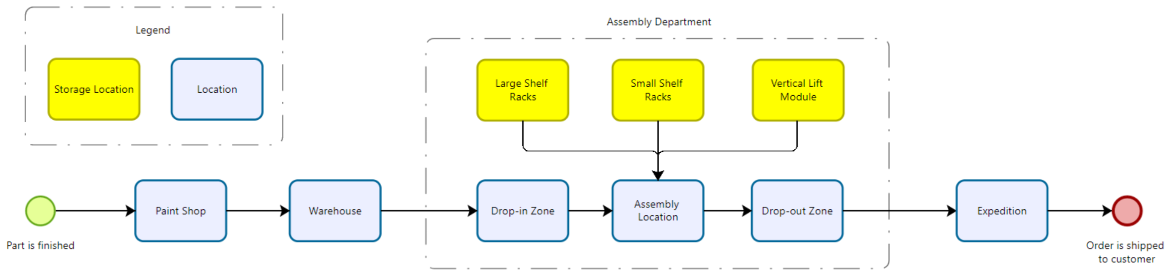


Figure 7: Movements to Collect Parts

This section will discuss the performance of these movements in two categories; first, by looking at the picking process within the warehouse. Then by looking at the picking process within the assembly department. Furthermore, this section includes an example with data for customer X to substantiate the number of movements.

2.3.2.1 From Warehouse

The movement during the warehouse picking process is from the forklift operator's current location towards the storage location and then to the assembly department. First, the operator places the parts in a drop-in zone in the assembly department. Next, the assembly worker collects the parts and moves them to the department's assembly location.

Company Y produces 6 cabinets for customer X every two weeks. Upon starting the order in the assembly department a forklift operator moves through the warehouse and has to collect a total of 14 box pallets and place them in the drop-in zone of the assembly department. Thus, resulting in 14 movements.

2.3.2.2 Within Assembly Department

Movement within the assembly department during the picking process is from the assembly location to the storage locations. Additionally, the assembly worker has to pick parts from the box pallets brought to the department by the forklift operator.

Once the box pallets are placed in the drop-in zone by the forklift operator, an assembly worker has to collect these box pallets and place them near the assembly location. The collection of the box pallets requires 14 movements to move the box pallets from the drop-in zone to the assembly location. Next, the assembly worker picks 14 parts from these box pallets. However, the assembly worker has to move along and go through several box pallets before finding the desired part, requiring additional movement along the box pallets.

Furthermore, the assembly worker collects parts from three different storage locations within the assembly department. These locations are small shelf racks, large shelf racks, and the vertical lift module. The distance between small shelf racks and the assembly location is so small that it is not considered a movement. Large shelf racks are further away from the assembly location. However, the assembly worker does not have to pick parts from this storage location to assemble the cabinet for customer X. Some parts are in the vertical lift module; in the case of the cabinet for customer X, the assembly worker has to move to the vertical lift module two times. Therefore, picking parts from the VLM requires 4 movements per assembly.

2.4 Conclusion

Two bottlenecks were identified based on the assembly department's performance analysis. The first one is the number of box pallets in the assembly department. Table 1 shows the surface area each object in the assembly department occupies. The pallets take up the most space on the work floor. Additionally, the other objects cannot be removed from the department since they are required to execute operations. Therefore, the bottleneck in terms of space is the number of pallets present in the assembly department.

The second bottleneck is the number of movements to transport box pallets from the warehouse to the assembly location. The total number of movements from the warehouse until the parts are on the product is 42. Because a forklift is not allowed in the assembly department, 28 movements are necessary to get the box pallets from the warehouse to the assembly location. Moreover, an additional 14 are necessary to pick the parts from the box pallets. These 14 movements are necessary to pick parts from the box pallets and are not reduceable. However, the 28 movements necessary to transport parts from the warehouse to the assembly location are reduceable. Therefore, this is the second bottleneck.

3 Literature Study

The performance analysis in Section 2.3 identified two bottlenecks: the number of box pallets in the assembly department and the number of movements to transport box pallets from the warehouse to the assembly location. Removing these two bottlenecks solves the problem. Therefore the solution must consider these bottlenecks. This chapter uses a literature study to find possible solutions to the problem while considering the two bottlenecks. Section 3.2 discusses a new layout as a possible solution. Finally, Section 3.3 discusses a kitting strategy as a possible solution.

3.1 LEAN

The LEAN methodology is a theory that continuously improves business processes and operations by eliminating waste. LEAN theory categorizes waste in Muda (waste), Muri (overburden), and Mura (unevenness). Muda defines activities that do not add value to the product or service. For example, unnecessary movement, unnecessary inventory, and idle time. Muri defines work overloads. LEAN theory strives to keep overtime to a minimum. Mura defines increases and decreases in demand or bottlenecks in processes. For example, when the speed of a process is not consistent over the length of the process, a bottleneck can be identified where the speed is lower than elsewhere in the process. LEAN theory strives for a consistent speed throughout the process.

The performance analysis identified two bottlenecks; these are within the categories of LEAN theory. First, the unnecessary movement is a form of Muda. The saved space is a peak in inventory and, therefore, a form of Mura. Therefore, the following ideas come from a literature study within the LEAN theory. The following sections discuss two solution directions based on LEAN theory.

3.2 Layout

3.2.1 Motivation

According to Theisens & Hampsink, (2017), it is possible to reduce the length of the movements by redesigning the layout of a facility or department. A reduction in movement is considered an increase in efficiency by LEAN theory. LEAN-theory states that unnecessary movement is considered waste since it does not add value to the product. Therefore, by reducing unnecessary movement, the efficiency of the assembly department will increase.

The redesign of the assembly department places the equipment and materials needed for assembling the product closer together. Therefore, the new layout reduces movement in terms of distance.

The main goal of the redesigned layout is to reduce movement between tools, storage locations, and assembly locations. According to Slack et al., (2016), minimizing the travel distance reduces movement. Therefore, the effectiveness of the layout can be calculated using the following formula:

$$Effectiveness\ of\ Layout = \sum F_{ij}\, D_{ij}\ for\ all\ i\ \neq\ j$$

Where

$$F_{ij} = journeys\ per\ period\ of\ time\ from\ work\ centre\ i\ to\ work\ centre\ j$$

$$D_{ij} = the\ distance\ between\ work\ centre\ i\ and\ work\ centre\ j$$

3.2.2 Benefits and Limitations

The benefit of a new layout is that it shortens the travel distance since it places the assembly location and resources (e.g. tools and storage locations) closer together. Thereby the length of the movements will be reduced.

Additionally, a new layout might save space. The main goal of the new design is to place resources closer to the assembly locations that use these resources more often. Furthermore, in designing the new layout, it is essential to consider where to place specific resources in the available space. The new layout might result in saved floor space, but the exact effects can only be determined after it is designed.

Designing a new layout also has limitations in achieving this research's goal. The performance analysis resulted in two bottlenecks: the number of box pallets in the assembly department and the number of movements to transport box pallets from the warehouse to the assembly location. A new layout reduces movement and might save space.

However, the movement reduction it results in is limited. The identified bottleneck is the movement from the warehouse to the assembly location. However, the new layout of the assembly department only reduces the length of the movement from the assembly location to the drop-in zone. Therefore, this solution does not reduce the number of movements, only the length of these movements.

Placing the assembly department closer to the warehouse is another way to reduce the length of the movements that are necessary to bring box pallets to the assembly department. However, it is impossible to bring these closer together since they are next to each other already, as seen in Figure 3.

3.3 Kitting

3.3.1 Motivation

Kitting is a strategy that creates kits, including the parts required for an assembly. So the quantities that arrive at the assembly department are the exact quantities to assemble the product. A kitting strategy is helpful to supply the assembly location and, in the process, reduce required space, ensure that all parts arrive at the assembly location simultaneously, and reduce movement during picking operations (Bozer & Mcginnis, 1992; Caputo et al., 2017; Hanson & Medbo, 2012).

According to Bozer & Mcginnis, (1992), a kit is “a specific collection of components and/or subassemblies that together (i.e., in the same container) support one or more assembly operations for a given product or shop order.” The kit and the strategy can be created in many different ways depending on the process. Therefore, no fully designed kitting strategies are effective in every production process.

Implementing a kitting strategy will place all the necessary parts in one kitting container. As a result, the kit reduces the total number of pallets in the assembly department during assembly. Furthermore, the kit reduces the number of movements from the warehouse since all the parts are in one container, not multiple box pallets.

3.3.2 Considerations

Based on the literature about kitting strategies, the design and implementation of the kitting strategy have some considerations. These considerations include the kit's design, time spent fetching parts, saved space, and logistical improvement.

The first consideration is the design of the kits. Errors in the kit's design can result in additional costs later in the production process (Fager et al., 2021). It is essential to look at the order of the assembly operations to ensure the kit suits the production process at the assembly department (Hanson & Medbo, 2012). Because packaging the kits in an unchronological order, might result in parts that are needed first end up at the bottom of the box. This would incur additional costs since an assembly worker must first unpack the kit to reach the required part.

Therefore, the kit must be packaged so that assembly workers do not have to unpack the kit before assembling but can work directly from the box.

Furthermore, it is essential to consider kitting errors when designing the kit. A kitting error is an error that occurs when creating the kit. Often occurring kitting errors with a description can be found in Table 2.

Kit error type	Description
Wrong component	A different component than required is included in the kit.
Missing component	A component is missing from the kit.
Defective component	A component with damages or manufacturing errors is included in the kit.
Wrong quantity	Too many or too few components of a part number are included in the kit.
Wrong position	A component is positioned incorrectly within the kit.

Table 2: Often occurring kitting errors (Hanson & Medbo, 2012)

Restoring these errors requires additional operations later in the process, which brings additional costs. Identifying the links between the errors and the kit design prevents the errors from occurring. Based on these links, the kitting operations can be adjusted (Fager et al., 2019).

The second consideration is the time spent fetching parts. The kitting strategy enables assembly workers to locate parts faster due to their logical location. Additionally, the parts are closer to the assembly location, resulting in less time spent on movement.

The consideration is the saved space. Since saving space is the original problem in the assembly department, this is one of the most important factors to consider in the kitting solution. This will be discussed later on in this section.

The fourth and final factor to consider is the number of logistical movements, including the creation of the kit and transport. According to Hanson & Medbo (2019), the creation of the kit is a waste, as described in LEAN theory, since the creation of the kit is time-consuming and does not add any value to the product. However, the investment in kitting can be returned later in the production process by saving time in assembly and transport. If kitting design is correct, it will save time in assembly because assembly workers spend less time fetching parts. Additionally, kitting can reduce the number of transportation movements due to the compactness of the kits. For the kitting solution to be successful, it is imperative to weigh the benefits against the limitations, such as invested time and time saved.

3.3.3 Benefits & Limitations

Table 3 displays the benefits and limitations of the kitting solution (Bozer & Mcginnis, 1992).

Benefits	Limitations
Saves manufacturing space	Kit assembly is time-consuming
Reduces WIP	Can require more storage facilities
Easier product changeover	Requires additional planning
Easier material delivery to the assembly location	Short kitting, in case parts are unavailable, a kit will be kitted incomplete
Increases productivity since parts are easier to find	A defective or failed part results in a shortage at the assembly location

Table 3: General advantages and limitations (Bozer & Mcginnis, 1992)

For the kitting strategy to be beneficial, the benefits must outweigh the limitations. The benefits and limitations are dependent on the implementation. For instance, one limitation of the kitting strategy is that it is time-consuming. However, if the kitting location is situated in the process where the parts are already packaged, the time spent to create the kits can be reduced. Therefore, this limitation becomes less influential in the feasibility of the solution. Furthermore, this research focuses on saving space and increasing efficiency. It might be necessary to make additional costs elsewhere to reach these goals as long as the benefits outweigh the limitations.

3.3.4 Economic Order Quantity

One of the requirements to successfully implement a kitting solution is to have the exact quantity of parts that go into the kit present at the kitting location (Fager et al., 2021). Therefore, adjusting the batch sizes is necessary. In order for the production to be as economical as possible, an Economic Order Quantity (EOQ) calculation can be used to find the batch size that is most economical in terms of production cost and storage cost.

The EOQ is a formula that weighs the costs of more production cycles against storage costs (Winston, 2004). There is an optimal solution to be found in terms of batch sizes. Although each batch size has setup costs, these costs consist of costs that need to be made without adding value to the product—for example, time spent on setting the machine to the correct settings. To minimize the setup costs, it would be best to produce in large batch sizes. Thereby the machine needs to be set to the correct settings fewer times.

However, producing in large batch sizes requires more storage space. For storing parts, company Y has storage costs. These storage costs are the value of the stored item multiplied by an interest rate. For example, if a product costs €100,- to produce and the interest rate of an investment is 10%. The company produces the product and stores it in the warehouse. Essentially the company is now storing €100,- in value. However, if the company invested this money and did not produce the product, it would have made a 10% profit on the €100,-. Thereby, storing the product costs the company the profit it would have made if it had invested the money.

The EOQ is calculated using the following formula:

$$EOQ = \sqrt{\frac{2DS}{H}}$$

$$D = Annual\ Demand$$

$$S = Setup\ Cost$$

$$H = Holding\ Cost$$

3.3.5 Packaging

3.3.5.1 Packaging Requirements

Company Y packages the same parts together since production takes place in batches. However, the kit consists of different parts, thus making the packaging more complex. There are three factors to consider when choosing a packaging method. These factors are potential damage to parts, picking of parts, and being broadly applicable.

Company Y produces parts with strict surface requirements, meaning scratches are not allowed. Therefore, it is essential to ensure that the packaging method does not damage the products during transport. Currently, most parts are packaged in a box pallet using styrofoam. The foam ensures that parts do not get damaged during transport.

Another factor to consider is part picking; it is desirable that assembly workers can pick each part without first having to remove another part. There are two ways for this. First, all parts can be removed individually without having to remove other parts. An example could be to place the parts in the box vertically, allowing the assembly worker to pull the part from the box. Another way is to create a chronological order in the kit. Thus, the part that is needed first is placed on top working down through the box.

Finally, ensuring that the way the kit is packaged applies to all other projects that go to the assembly department is essential. Too specific packaging is costly due to the large variety of packaging required to transport the products. Also, the storage of these racks would take up space, while saving space is one of the priorities of this research. Therefore, applying the packaging method to all projects would be best without requiring particular materials.

These requirements will be transformed into criteria to determine the best suitable packaging solution.

3.3.5.2 Minomi

Set Part Supply (SPS) is a kitting process developed by Toyota; SPS reduces wastes known in LEAN theory as Muda (waste), Muri (overburden), and Mura (Unevenness) (Fansuri et al., 2017). This kitting process uses the Minomi concept, meaning that this supply strategy uses no additional packaging material to move the parts to the assembly location (Hanson, 2011). Figure 8 shows an example.

Figure 8: Example of Minomi Concept (Fansuri et al., 2017)

The main advantage of Minomi is the reduced handling time when placing parts in a rack or container for transportation. In addition, Minomi enables the part to rest on a frame without needing to be packaged to ensure the part does not get damaged during transport to the assembly location. The elimination of packaging is a form of waste reduction, thus making Minomi a LEAN concept.

3.4 Conclusion

This chapter suggests two alternative solutions, based on LEAN theory, to resolve the bottlenecks found in Section 2.3. The first solution is to redesign the layout of the assembly department. The second solution is to create a kitting strategy.

The performance analysis shows two bottlenecks. Therefore, the extent to which the two possible solutions address the bottlenecks is essential to determine the best possible solution. The two bottlenecks are the number of box pallets in the assembly department and the number of movements from the warehouse to the assembly location. Table 4 uses the bottlenecks as criteria to compare the two possible solutions.

There are three different scores to give each criterion. Low, average, and high. Low means that the solution has a negligible effect on the criterion. High means that the solution has a high positive effect. Average indicates that there is some effect.

Solution	Impact on space	Impact on movement
Layout	Low	Average
Kitting	High	High

Table 4: Impacts of Solutions on Bottlenecks

The effect of the new layout on saving space depends on the design of the new layout. However, the effects of the new layout will not address the bottleneck of too many box pallets in the assembly department. Instead, it will make more efficient use of the space. The new layout addresses the bottleneck for movement directly. However, it only addresses movement within the assembly department and does not decrease the number of movements but shortens them. Therefore, the effect on movements is average.

A kitting strategy significantly impacts saved space since it ensures that only the desired materials go to the assembly department. Therefore, the number of box pallets that must be present in the assembly department simultaneously reduces. Additionally, a new packaging method could save even more space. Since it places parts in a container more efficiently, thus requiring less space. Furthermore, a kitting strategy has a high impact on movement. Due to the new packaging method, fewer box pallets move to the assembly department.

Kitting is the most profitable solution based on each solution's effect on the bottlenecks.

4 Kitting Solutions

This chapter discusses a variety of kitting solutions. The kitting strategy consists of three aspects for which multiple solutions are possible. These aspects are picking, production, and packaging of the kit. First, Section 4.1 discusses the picking of the parts for the kit. Next, Section 4.2 discusses what needs to be changed in production to cohere with the different picking strategies. Next, Section 4.3 creates three detailed solutions regarding picking and production. Finally, Section 4.4 provides a variety of packaging solutions. The packaging solutions stand apart from the picking and production solutions since they are independent.

4.1 Picking

As discussed in Section 3.3.2, the creation of the kit is a waste. The operation is time-consuming and does not add any value to the product. However, a kitting strategy can save time later on in the process. Kitting is a more efficient strategy as long as the invested time is shorter than the gained time. The kit creation location is essential to ensure minimal time spent creating the kits. This section discusses two kit creation locations, the paint shop and the warehouse.

4.1.1 Paint-Shop

After considering the current flow of materials through the facility, the paint shop was the last department parts go through before reaching the assembly department. Once parts reach the end of the paint shop, they are packaged and placed in the warehouse for intermediate storage. Sometimes, the parts are transported directly from the paint shop to the assembly department. Since the parts are already being packaged at the end of the paint shop, this location seems to be where the least time would be lost in creating the kits.

However, one of the conditions of kitting, as discussed in Section 3.3.2, is that all the necessary parts should be in the kit. If the kit is incomplete, the additional cost to pick missing parts makes the kitting strategy less efficient. So it is essential that all the parts are present in the correct quantities during the creation of the kit. As it may, company Y currently uses a make-to-order strategy (MTO). This means that production starts when placing an order. For example, when planning an order of 2 products, all the independent parts are planned for production based on current stock. However, the cutting department is free to alter the batch sizes to keep the setup cost as low as possible, thereby maximizing production time. This results in inconsistent batch sizes throughout the facility. So not all the crucial parts that should be present when creating the kits will be present at the end of the paint shop since some parts were produced earlier and are either in the warehouse or the assembly department.

Furthermore, sometimes the batch size will be too big to create the desired number of kits. In this case, the excess number of parts must be packaged and stored in the warehouse. The additional movement to collect these parts when creating the kits is a waste and, therefore not efficient.

Therefore, production needs to be altered if the paint shop is chosen as the location where the kits will be created. All this is to ensure that when the kits are created, all the parts are present in the correct quantities.

4.1.2 Warehouse

The second location is the warehouse. As mentioned earlier, parts are in the warehouse before being moved to the assembly department. This creates the possibility of creating the kits in the warehouse. Once the assembly order starts in the assembly department, a logistics worker will pick the desired parts from the warehouse with a container.

Section 4.3 discusses the alternative containers. The logistics worker requires a stacker[4]to move box pallets from the large shelf racks and pick the parts. When all parts are in the container, the filled container is moved to the assembly department to start the product assembly.

This picking location does require several additional movements, resulting in a more time-consuming process. First, the picker has to move through the warehouse to collect the parts. These are close to each other to keep the movements to a minimum. The picker has to take box pallets from the shelf racks, pick only what is required, and then move the pallet back into the shelf rack. In terms of LEAN theory, movement is a waste. However, by creating additional movement here, movement will be reduced in the assembly department since picking from the container will be more efficient. This solution does not require company Y to adjust the batch sizes. The logistics worker can pick from the stock in the warehouse where all desired parts are present.

4.2 Production

As mentioned in Section 4.1.1, if the picking location is at the end of the paint shop, batch sizes need to be altered to prevent additional waste in terms of movement. Currently, the batch sizes can differ too much per production cycle. This would result in a shortage or excess number of parts at the end of the paint shop where the kit creation takes place. Therefore, the exact number of parts needed to create a specific number of kits must be produced in each batch. To ensure this is the most economical and efficient batch size, an EOQ calculation has been made. Since company Y produces a wide variety of assemblies, one has been chosen to show the calculation: assembly X. The following sections explain the calculation.

4.2.1 Parts

Assembly X is a cabinet that company Y produces in batches of 4 once every two weeks. The cabinet consists of multiple parts, of which company Y produces 20. The other parts come from external suppliers. Not all the parts that company Y produces will be placed in the kit. Some of the parts are small and produced in large batch sizes. These parts are stored within the assembly department and will not be in the kit. The only parts in the kit are large panels that go through the paint shop. Filtering parts from ISAH results in the following list of 13 parts.

Article Number	Length (mm)	Width (mm)	Height (mm)	Quantity for 1 Cabinet
248523	1299.3	789.5	43	1
251931	643.4	448	25	1
251932	643.4	448	25	1
256590	823.3	261.6	101	2
256591	823.3	261.6	101	2
256592	790	66.5	61.75	2
256589	790	66.5	61.75	2
256588	667.5	180	53.7	2
279918	1600	800	271.3	1
256511	877.5	595.2	133.6	1
256519	456.5	352.5	55	1
256517	858.5	65.5	35	1
256518	858.5	65.5	35	1

Table 5: Parts Chosen for EOQ Calculation with Measurements

[4] A stacker is an electric powered device that is used to move pallets. Furthermore, it can elevate pallets in order to store them in large shelf racks.

4.2.2 Economic Order Quantity

The EOQ calculation requires three values to be known. These include annual demand, setup cost, and holding cost. The annual demand for the cabinet has been determined based on production history and was estimated to be 70. However, the required quantity of some of the parts of the cabinet is not one but two. Therefore, these parts have an annual demand of 140.

The setup costs were calculated using data from ISAH. Each part has a specific routing through the facility passing through multiple departments. Each of these departments has its own setup time and hourly rate. From ISAH, the setup time was extracted and multiplied by the hourly rate for each department. This results in the setup cost for each department per part.

Company Y does not have a set holding rate. Therefore, the interest rate of the production cost replaces the holding cost. The production cost was extracted from ISAH using three different production cycles. Therefore, the interest rate for this calculation is 10%.

After these values were determined, the EOQ was calculated three times using the following formula:

$$EOQ = \sqrt{\frac{2DS}{H}}$$

The data on which the calculation is based came from three production cycles—each with different quantities. Therefore, the calculation is conducted three times to ensure the EOQ is valid.

This results in the following EOQs:

Article Number	EOQ1	EOQ2	EOQ3	Average
248523	28	27	27	**27**
251931	34	34	34	**34**
251932	35	34	34	**34**
256590	49	50	49	**49**
256591	49	50	49	**49**
256592	47	48	47	**47**
256589	47	48	47	**47**
256588	50	51	50	**50**
279918	18	18	18	**18**
256511	32	32	32	**32**
256519	36	37	37	**37**
256517	36	36	36	**36**
256518	36	36	36	**36**

Table 6: EOQ for all Kitted Parts

4.2.3 Comparison

As mentioned in Section 4.2, kitting requires the exact number of parts needed to create a specific number of kits to be produced in the same batch. This means that no leftover parts are present after the kits have been created. Therefore, each part that is included in the kit should be according to the desired quantity for one cabinet, as shown in column 4 of Table 7. Based on the EOQ calculations, this results in the batch size, as shown in column 5 of Table 7.

Based on the EOQ calculation, company Y would have to produce a total of 432 parts instead of 284. However, this increase in batch sizes is too significant for the warehouse to contain. Therefore, the batch size based on EOQ calculation is not feasible for company Y.

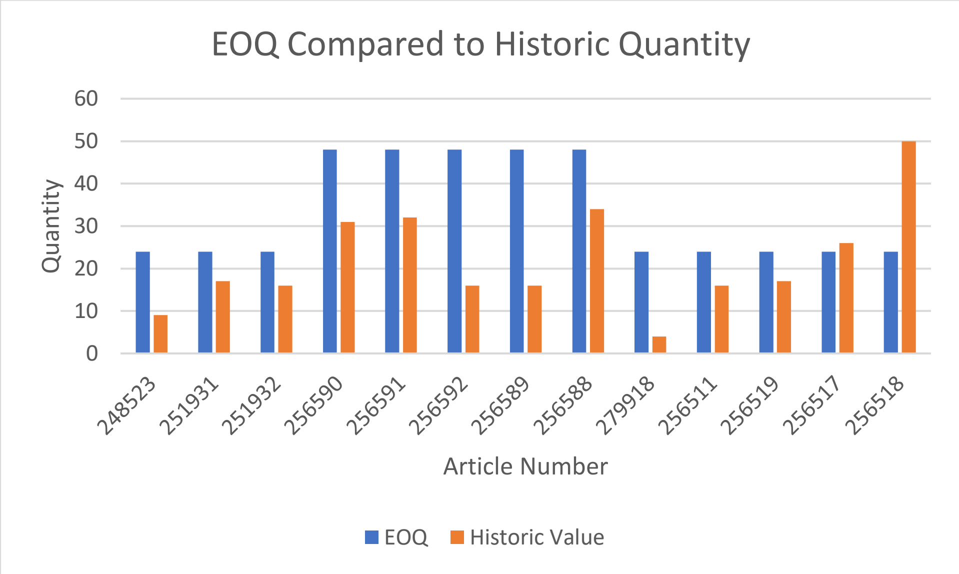


Figure 9: EOQ Compared to Historic Quantity

Figure 9 compares the batch sizes based on the EOQ calculation and the historic batch sizes. In addition, it visualizes how the new batch sizes would increase the inventory company Y would have to provide to store all the parts.

Transforming the EOQ formula shows that increasing the batch size toward the calculated EOQ is more economical for company Y. Therefore, there exists another possibility to increase the batch size to an amount that is more economical and feasible considering the storage capacity in the warehouse. These batch sizes are in the same ratio as the original EOQ since each kit contains all the parts for one product. Additionally, the batch sizes are of a size that is comparable with the historical value to ensure it fits in the warehouse, as shown in column 6 of Table 7.

Article Number	EOQ	Historic Quantity	Quantity for 1 Cabinet	Batch Size Based on EOQ	Proposal Based on Historic Value
248523	27	9	1	24	12
251931	34	17	1	24	12
251932	34	16	1	24	12
256590	49	31	2	48	24
256591	49	32	2	48	24
256592	47	16	2	48	24
256589	47	16	2	48	24
256588	50	34	2	48	24
279918	18	4	1	24	12
256511	32	16	1	24	12
256519	37	17	1	24	12
256517	36	26	1	24	12
256518	36	50	1	24	12

Table 7: EOQ Compared to Historic Value

4.3 Solutions for Picking and Production

Three solutions were created based on Sections 4.1 and 4.2 of this chapter. These solutions discuss the location of the kit creation and the strategy.

4.3.1 One Kit – Paint Shop

The first alternative is to create the kit at the paint shop. The analysis of the flow of material through the facility determines that all large parts that need to be in the kit will, at some point, move through the paint shop. Here the same parts are packaged together and moved to the warehouse or directly to the assembly department. However, the parts do not arrive in the correct quantities but in more efficient quantities for the production departments. Therefore, the production planning needs to be changed to batch sizes that align with the production orders. This can be achieved by using the calculation in Section 4.2. This calculation includes the ratio between parts to create an exact number of kits. This results in the exact quantity of parts arriving at the end of the paint shop. Therefore, the kit can be created after painting the parts and directly putting the parts together in the container for assembly. Figure 10 illustrates the process for the One Kit – Paint Shop Alternative.

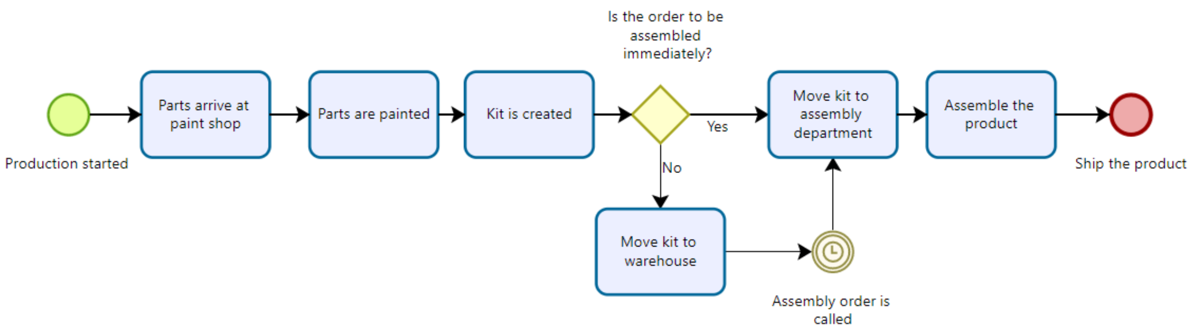


Figure 10: Flow Chart for One Kit Paint Shop Alternative

This strategy does require strict planning. For example, if one of the parts arrives late at the end of the paint shop, the entire kit will be held up. Alternatively, the kit will be incomplete, and an additional transport will be required to move the late part to the assembly department.

4.3.2 One Kit - Warehouse

The second alternative solution does not change production directly. Company Y can continue to produce parts as they are currently doing. Upon finishing a part, it moves to the warehouse for storage. Eventually, the assembly order starts. This is when a logistics worker will pick the desired parts from the warehouse with a container. The logistics worker requires a stacker to move box pallets from the large shelf racks and pick the parts. When all parts are picked, the filled container is moved to the assembly department to start the product assembly. Figure 11 illustrates the process for the One Kit – Warehouse Alternative.

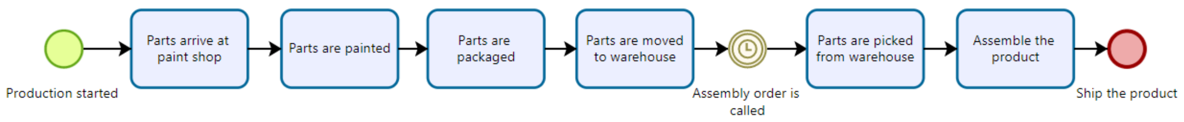


Figure 11: Flow Chart for One Kit Warehouse Alternative

To keep picking times to a minimum, placing the parts that are picked together close to each other in the warehouse is the most efficient. Company Y currently uses flexible storage locations. Meaning that parts can be stored at any free spot in the warehouse. When storing a box pallet in the warehouse, the forklift operator scans the box pallet and the storage location code. This links the box pallet to the specific storage location and shows this in the ISAH. Due to this system, it is possible to reserve specific locations for specific parts. This enables the possibility of storing parts from the same assembly close together.

4.3.3 Multiple Kits

Another alternative is the design of multiple kits. Based on production history, parts with the same batch size would be kitted together. Thus, several kits can be picked from the warehouse or moved from the paint shop to the assembly department directly.

A big limitation of this strategy is the lack of consistency in batch sizes. Based on production history, the batch sizes vary a lot based on availability and stock. This results in a problem when the kits are created since not all the parts included in the kit will be present in the desired quantities. Eventually, this will result in several parts, of which there will be a remainder after creating the kits. These parts will then be packaged separately and moved to the warehouse. The next time the order is called, these parts will have to be picked separately in the warehouse. This results in an inconsistent and complex flow of materials since parts will be elsewhere every time.

Consistent order quantities solve this problem. However, company Y wants the flexibility to remain in the production departments so they can adjust batch sizes to maximize production time. Therefore another solution is needed to ensure a more consistent flow of material. This can be achieved by creating clusters of parts that are in the same kit. Once parts are being produced, all the parts in the same cluster must be produced in the same quantities. So the exact quantities arrive at the end of the paint shop and create complete kits. The difference with this solution is the number of kits that are created each production cycle since batch sizes can vary. However, due to the clusters, each part that is kitted together with another part will be produced in the same quantities to ensure complete kits can be created without excess parts.

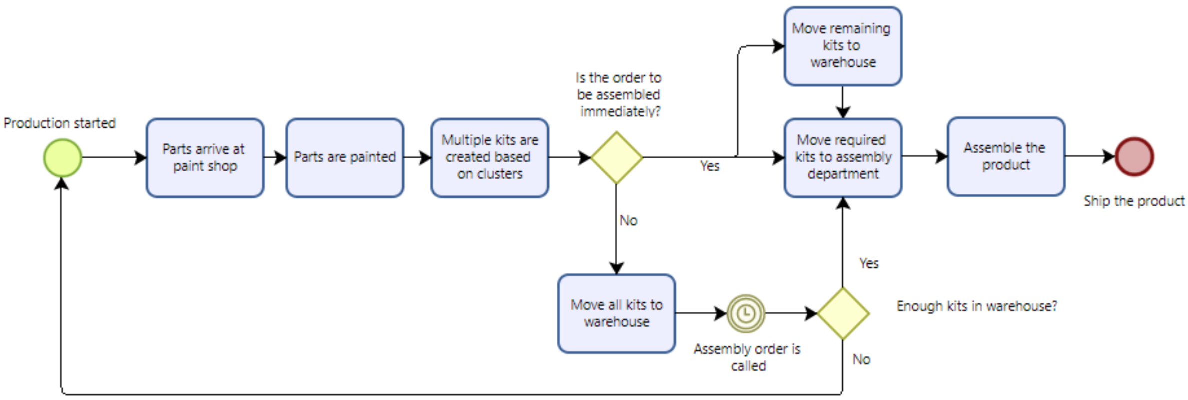


Figure 12: Flow Chart for Multiple Kits Paint Shop Alternative

4.4 Packaging

This section discusses multiple forms of packaging; each has its benefits and limitations. However, two critical factors are damaging parts and order picking. The alternatives include a box pallet, A-rack, and two Minomi concepts (horizontal and vertical).

4.4.1 Box Pallet

Company Y currently uses the box pallet to transport parts through the facility. It consists of a regular euro pallet combined with one or multiple upstanding edges, as seen in Figure 13. The parts in this container need to be protected with some additional styrofoam to prevent them from getting damaged during transport. Parts will be placed in the box pallet vertically to ensure that assembly workers can pick any part from the box without having to remove other parts. A restriction with the use of the box pallet is the size of the parts. When parts become too big to be in the box, they must be transported separately to the assembly department.

Figure 13: Example of a Box Pallet with Upstanding Edge

Company Y uses box pallets with size 1200mm x 800mm. Each upstanding edge has a height of 500mm, and a maximum of six edges can be on top of each other.

4.4.2 A-Rack

Figure 14: Example of an A-Rack

The second alternative is using an A-rack. Just like the box pallet option, the A-rack enables vertical storage of the parts, thus requiring less space. However, during transport the parts are at risk of falling from the A-rack. A strap can prevent the parts from falling. Additionally, parts will be placed against each other, possibly damaging the parts. A protective material between the parts ensures the parts do not get damaged during transport. Furthermore, the A-rack design makes it harder to pick parts freely since another part might obstruct the desired part. A specific sequence in which the parts are on the rack ensures that moving other parts is unnecessary.

4.4.3 Minomi Concept

The Minomi concept is a LEAN concept to reduce waste, as described in Section 3.3.5.2. The most significant advantage of the Minomi concept is that no packaging materials, such as styrofoam, are required to package the parts. The Minomi concept places parts in racks, similar to Figure 8. However, the parts for company Y are often larger; thus, the rack design needs to be adjusted. Additionally, Minomi is usually used to transport batches of the same part to an assembly location. Applying the Minomi concept to company Y will not be transporting batches but kits. Therefore, company Y handles a wider variety of parts in the same rack. Based on the literature study, the Minomi concept is adapted to create two different designs.

4.4.3.1 Vertical Minomi Concept

The vertical Minomi concept stores the parts vertically in the racks, similar to Figure 8. However, the design had to be adjusted due to more significant parts. The design consists of a box which is placed on wheels. The parts will not be placed against each other, instead, there will be multiple slots in which a part can be placed, enabling free picking. The box has vertical slots which can be adjusted in width, since the parts also vary in width. The inside of the box is covered in a protective material to prevent damages to parts. Furthermore, this foam ensures that no additional packaging materials are required. To visualize this solution a SolidWorks model has been created.

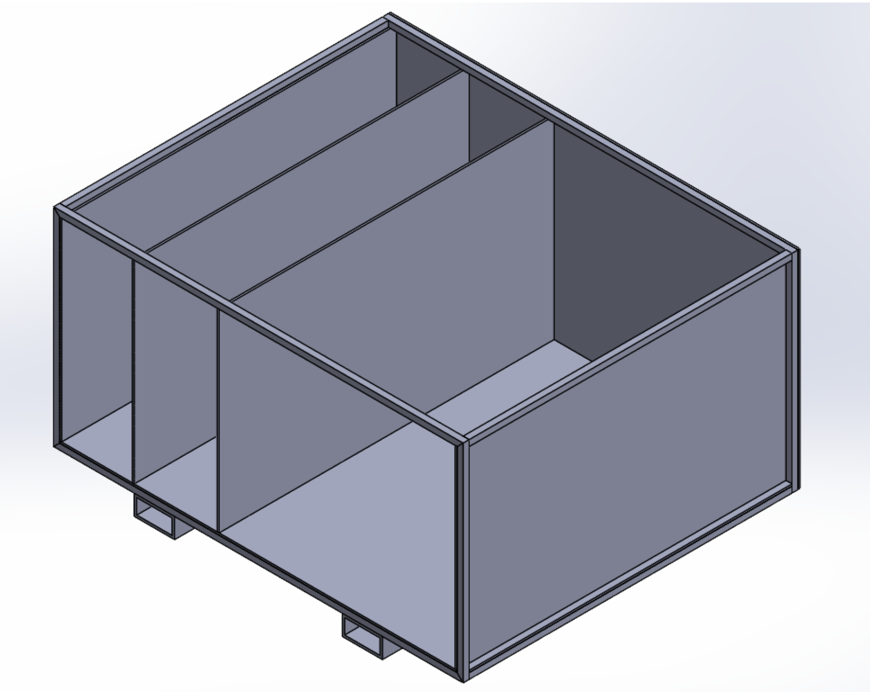


Figure 15: Initial Design Vertical Minomi Frame

4.4.3.2 Horizontal Minomi Concept

The horizontal Minomi concept stores parts horizontally instead of vertically, as seen in Figure 16. A protective foam is on the bars on which the part rests. Thus, the part will not get scratched during transport. As the definition of Minomi describes, this way of packaging uses no additional packaging materials. Furthermore, the design enables the assembly worker to pick each part without first having to move other parts. Finally, the height between the horizontal bars can be adjusted easily; thus, this design suits all possible parts in terms of height differences.

This design has a few limitations; the rack size is an essential factor. If the distance between the bars is too large, smaller parts will not fit. Large parts will stick out over the frame's border if it is too small. A part that sticks out over the edge of the frame has a higher risk of damage during transport. Additionally, large parts that stick out can bend under the force of their weight if not supported sufficiently. Therefore, the rack is adjustable in width as well. By making the bars moveable towards and from each other.

Figure 16: Example for Horizontal Minomi Concept (Material Handling Wholesaler, 2015)

4.5 Conclusion

This chapter includes design alternatives for picking, production, and packaging. The picking and packaging solutions are dependable on each other. Therefore, Section 4.3 discusses them together in 3 alternatives. Then, section 4.5 introduces 4 different packaging methods. Finally, chapter 5 will compare all these solutions and choose one of them as the solution to solve the problem.

5 Choice of Solution

Chapter 5 compares solutions based on the alternative solutions from Chapter 4. First, in Section 5.1, a production and picking strategy will be chosen and substantiated. Next, in Section 5.2, a packaging method will be chosen using a Pugh matrix analysis (Heerkens & van Winden, 2017).

5.1 Production & Picking

Three different strategies for production and picking have been discussed in Chapter 4. All these alternatives achieve this research's primary goals: saving space and increasing efficiency in the assembly department. However, each achieves these goals to a different extent.

5.1.1 Criteria

The evaluation uses six criteria to compare the solutions. The first two criteria are the bottlenecks from Chapter 2: saving space and reducing movement. The other four criteria are results that come with choosing a specific kitting alternative.

5.1.1.1 Space

The first criterion is space. This research's first and primary goal is to save space in the assembly department. Therefore, it is essential to consider how much space each alternative saves compared to the other.

5.1.1.2 Movement

The second criterion is movement. Movement is to be reduced in the new situation to increase efficiency according to the research goal. Therefore, the decrease in the movement must be compared between different solutions to determine which solution increases the efficiency the most.

5.1.1.3 Batch Size

One of the alternatives requires additional adjustments to the existing process. One of these is the batch size in which company Y produces parts. Therefore, it is essential to consider how much freedom remains to alter batch sizes between production runs since most parts are combined into each other in terms of batch sizes due to the creation of the kit.

5.1.1.4 Kit Creation

The location and process of the kit creation differ per alternative. Therefore, it is necessary to look at the additional movement required to create the kit.

5.1.1.5 Production Cost

By altering the batch sizes, the production cost might increase or decrease. Therefore, the solution choice considers the production cost.

5.1.1.6 The complexity of the Solution

The new process that comes with each solution has a certain degree of complexity. This complexity can possibly result in errors, such as the kitting errors discussed in Section 3.3.

5.1.2 Performance & Choice

Table 9 shows the performance of each of the three alternatives based on the five criteria. Table 8 shows the possible options to score the criteria.

Options	Description
Positive	Positive effect on the criterion
Average	Average effect on the criterion
Negative	Negative effect on the criterion
Variable	The effect is dependent on each independent cycle. Therefore it is not possible to determine if the effect is positive or negative

Table 8: Scoring Options for Kitting Strategies

Alternatives / Criteria	One Kit – Paint Shop	One Kit – Warehouse	Multiple Kits – Paint Shop
Space	<u>Positive</u> One kit reduces the required space in the assembly department a lot	<u>Positive</u> One kit reduces the required space in the assembly department a lot	<u>Average</u> Multiple kits do not reduce the space as much as one kit
Movement (efficiency)	<u>Positive</u> The kit is created in a place where there already was the movement before so there is no additional movement in the creation of the kit Movement from the paint shop to the assembly department is reduced since all the parts are placed in one container instead of multiple containers Movement within the department is reduced since parts can be located in fewer locations thus reducing the picking movement	<u>Negative</u> Parts are moved to the warehouse as they were before thus no reduction in movement from the paint shop to the warehouse The kit is created in the warehouse thus requiring additional movement to pick the parts and create the kit Movement within the department is reduced since parts can be located in fewer locations thus reducing the picking movement	<u>Average</u> Movement from the paint shop to the warehouse is reduced since parts are packaged in multiple kits, however not as much compared with the one-kit paint shop solution Movement from warehouse to assembly department is reduced but not as much as the one kit paint shop solution Movement within the department is reduced since parts can be located in fewer locations thus reducing the picking movement
Freedom in batch sizes	<u>Negative</u> All parts need to be produced in specific quantities	<u>Positive</u> Parts can be produced in any desired batch size	<u>Average</u> Batch sizes can vary as long as all parts within the cluster have the same batch size
Time spent creating the kit	<u>Positive</u> Since in the current situation the products are already packed the additional time to create the kit is kept to a minimum	<u>Negative</u> Products need to be packaged twice and picking from the warehouse is time-consuming	<u>Positive</u> Since in the current situation the products are already packed the additional time to create the kit is kept to a minimum
Production Cost - Economic Order Quantities	<u>Average</u> By creating the kit here the batch sizes are no longer flexible. Thus an optimum batch size must be created for each part that corresponds with all the other parts.	<u>Variable</u> Since the batch size is not consistent the production cost will vary per production order	<u>Positive</u> Parts that have similar EOQ and batch size history will be produced in the same batch sizes. Resulting in a low production cost

Complexity of the solution	Average Due to the complexity of the solution in terms of batch sizes. But there is not additional complexity in the number of kits.	Positive No complexity in terms of batch sizes or number of kits. This solution only changes logistics.	Negative Due to the complexity of the solution in terms of batch sizes and the number of kits

Table 9: Performance of Kitting Strategy Alternatives

The multiple kit–paint shop alternative is scoring the lowest. Therefore, this eliminates this alternative. The 2 remaining alternatives both have 3 positive criteria. However, the one kit–paint shop alternative scores better on space reduction and movement reduction, which are the two main goals of this research. Therefore, the one kit–paint shop alternative is the best-performing solution. This solution does require set batch sizes, which might increase production costs. However, these set batch sizes mean that only what is needed is produced, thereby reducing storage costs. Additionally, company Y has the opportunity to work away the backlog they are currently facing.

The one kit–paint shop alternative is the most rewarding alternative. However, it does require company Y to produce set batch sizes. This limits the flexibility in batch sizes for kitted parts. To prevent the set batch sizes, selecting the one kit – warehouse alternative is possible. This alternative supports free batch sizes. However, it is less rewarding regarding movement, space, and economic production.

5.2 Packaging

This section will compare the different packaging solutions using a Pugh matrix analysis. In a Pugh matrix analysis, criteria are created for the solutions to be graded. Eventually, the best-performing alternative becomes the chosen solution.

5.2.1 Criteria & Weights

Based on the requirements in Section 3.3.5.1 and the advantages & disadvantages in Section 4.3, 7 criteria were chosen. Furthermore, each criterion has a weight based on its importance. The production manager validates these weights. Table 10 displays these weights.

Criteria	**Description**	**Weight**
1. Packaging	Does the solution require additional packaging materials?	0.10
2. Picking	How easily can parts be picked from the container?	0.20
3. Large Panels[5]	Does the container support transportation of large panels?	0.10
4. Small Panels[6]	Does the container support transportation of small panels?	0.10
5. Moveability	Is the container easy to move?	0.10
6. Damages	What is the chance of damage?	0.20
7. Saved Space	How much space does the new packaging container save compared to each other?	0.20

Table 10: Decision Criteria and Weights

Section 3.3.5 discusses four of these criteria. These are damage to parts (6), picking of parts (2), and being broadly appliable (3 & 4). The other three: packaging (1), moveability (5), and saved space (7) are criteria that came with the design of the different containers.

The importance of that criterion to company Y determines the weight of each criterion. The most important criteria are: picking (2), damages (6), and saved space (7). Picking and saved space cohere with the primary goal of this research. To save space and increase efficiency. The criterion for damages is also essential. If the new container has a high chance of damaging the parts, it brings additional costs, which company Y wants to prevent. Therefore these are the three most essential criteria.

Criteria 1, 3, 4, and 5 are additional criteria that show how compatible the new container is with the kitting strategy.

[5] Large panels are identified as larger than what fits in a box pallet (width > 1100 mm, height > 1500 mm)
[6] Small panels are identified as panels that fit within a box pallet (width < 1100 mm, height < 1500 mm)

Each criterion is scored on a scale of 1 to 5. The scales and descriptions are shown in Table 11.

Score	Description
1	Very bad
2	Bad
3	Neutral
4	Good
5	Very good

Table 11: Description of Weights

5.2.2 Scores

The alternatives are scored in Table 12 and multiplied by the assigned weights. Based on the scoring from Table 11, the design alternative vertical Minomi receives the highest score and becomes the solution. The scoring is based on the input from the production manager, assembly workers, and literature. Furthermore, the production manager and assembly workers confirm the decision. They also expressed their preference with the vertical Minomi concept, thus confirming the choice.

Vertical Minomi scores are high on all the essential criteria (2, 6, and 7). In comparison, the alternatives score high on one or two of these criteria.

Criterion 2 concerns how easy it is to pick parts from a container. The Minomi concept is a design that concerns itself with easy picking from containers without having to use additional packaging materials. Therefore, the two Minomi alternatives score high on this criterion.

Criterion 6 is where vertical Minomi differs a lot from horizontal Minomi. The chance of damage when using horizontal Minomi is considerably more significant than vertical Minomi. When a forklift is transporting the horizontal Minomi container and drives into a shelf rack, all the parts are damaged due to their horizontal orientation. The vertical Minomi concept only damages the front part since that is the only one that could potentially make contact with the shelf rack.

The last important criterion is saved space, which is the primary goal of this research. Since the specific dimensions of the design alternatives are unknown, only estimates can be given based on how they would perform compared to each other. Since the box pallet cannot contain all parts, some parts must be stored outside the box pallet. Therefore this alternative scores lowest on this criterion. Furthermore, storing parts horizontally requires more space floor space than storing it vertically. Therefore the horizontal Minomi concept scores lower than the vertical Minomi concept. Finally, the A-rack and vertical Minomi alternatives are almost identical in terms of floor space. Therefore these are scored equally high.

Alternatives / Criteria	Weights	Box Pallet		A-rack		Vertical Minomi		Horizontal Minomi	
		Score	**Weighed Score**	**Score**	**Weighed Score**	**Score**	**Weighed Score**	**Score**	**Weighed Score**
1. Packaging	0.10	1	0.10	2	0.20	5	0.50	5	0.50
2. Picking	0.20	2	0.40	2	0.40	5	1.00	5	1.00
3. Large Panels	0.10	1	0.10	5	0.50	5	0.50	2	0.20
4. Small Panels	0.10	5	0.50	2	0.20	5	0.50	2	0.20
5. Moveability	0.10	5	0.50	5	0.50	5	0.50	4	0.40
6. Damages	0.20	5	1.00	4	0.80	4	0.80	1	0.20
7. Saved Space	0.20	3	0.60	5	1.00	5	1.00	4	0.80
Total Score	**1.00**		**3.2**		**3.6**		**4.8**		**3.3**

Table 12: Weighed Scores per Alternative

5.3 Investments

The kitting strategies do not require additional financial investments since it is a strategy that changes the process. All the resources to implement this strategy are already present. Therefore, the strategy requires no additional investments.

The new packaging method requires a financial investment to produce the containers. Company Y is capable of producing these containers internally. The number of containers depends on how many projects are compatible and profitable with the new strategy. Furthermore, the specifications are not yet complete, and the design is unfinished. Therefore, it is hard to estimate the production cost for these containers.

5.4 Impacts

The kitting strategy does not influence the production processes until the paint shop or the warehouse, depending on the chosen kitting strategy.

If the one kit–paint shop alternative is chosen, there is almost no additional movement when creating the kit. Currently, the paint shop places parts in a box pallet at the end of the paint shop. By changing the box pallet for the container, there is no additional movement in creating the kit.

If the one kit – warehouse solution is chosen there is some additional movement when creating the kit. The process remains the same until parts are placed in the warehouse. However, when creating the kit a logistics employee has to move through the warehouse to pick the desired parts and place them in the kitting container. This is additional movement compared to the old situation. However, there is also still movement reduction since it is no longer required to pick independent pallets and move them independently to the assembly department.

5.5 Returns

5.5.1 Space

Both solutions result in saved space and movement reduction, regardless of the chosen solution.

The saved space remains the same for both solutions. In case of cabinet X the original 14 pallets are replaced with 3 containers. Originally the box pallets occupied approximately 14 m^2, the 3 kitting containers will occupy 6 m^2. Resulting in a space reduction of 8 m^2 or 57.14%. This is only the case for cabinet X. The gained floor space will also increase when implementing the solution to more projects.

5.5.2 Movement

The movement reduction is dependent on which solution is chosen. The one kit – paint shop solution reduces movement from the paint shop to the assembly department and within the assembly department. In case of cabinet X movement from the paint shop to the assembly location reduces from 28 to 6 movements. This reduces movement by 78.57%.

The one kit – warehouse solution reduces movement from the warehouse to the assembly location from 28 to 12 movements. This reduces movement by 57.14%.

5.6 Considerations for Implementation

This section addresses what to consider when implementing the chosen solutions in chapter 5. First, the approach will be discussed in Section 5.5.1. Next, section 5.5.2 discusses the costs that come with the implementation. Next, Section 5.6.3 discusses the risks. Finally, Section 5.6.4 provides an evaluation to be conducted after the strategy has been implemented.

5.6.1 Approach

5.6.1.1 Preparation

This section discusses the necessary preparations before the solutions can be implemented.

Construction of Container

The solution requires the production of the packaging container from Section 5.2. This container needs to be further designed with the correct requirements to ensure that the parts are secure and cannot be damaged by the container. Company Y has the knowledge and equipment to design and produce this container themselves.

New W-Number

As explained in Chapter 2, every operation within company Y has its own W-number. This number shows employees what operation to execute. The picking operation from the warehouse is new therefore it requires a new W-number.

Incorporate the order of parts in the picking list

The parts that need to be picked from the warehouse are shown on a picking list. This list should include where the parts are located in the warehouse. Furthermore, the order in which parts appear on the list should be the order in which they are picked. Since this order is also the order in which they are assembled. Even though the new container enables free picking, company Y wants this additional requirement to minimize the chance of damaging parts during the picking operation.

Explanation of new system to involved employees

The new strategy (and W-number) need to be explained to the employees involved with the new strategy. These include the logistics workers and assembly workers. The logistics worker responsible for picking the parts from the warehouse should know how to use the picking list and place the parts in the container. The assembly workers need to be explained that they are no longer responsible for picking parts from the warehouse.

5.6.1.2 Realization

Once the preparations are in order the new process can be used. Figure 17 shows a detailed, step-by-step process flow and operations approach.

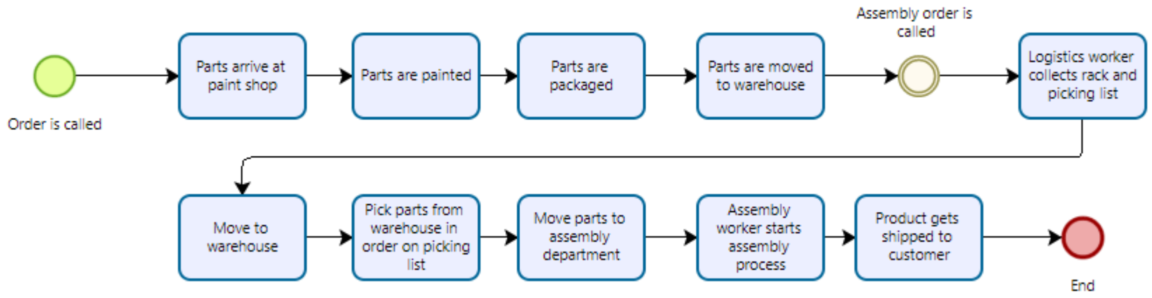


Figure 17: Detailed Process Flow of Picking Strategy

5.6.1.3 Social Implementation/Organization & Responsibilities

The production manager and team leader of the assembly department will be responsible for implementing the new strategy and executing the new process. However, the employees are the ones who will need to work according to the strategy. Therefore, ensuring the employees implement the new strategy is vital. This can be done by showing the new strategy and explaining the benefits of the new way of working. Ultimately, the new strategy lowers the workload for the employees in terms of time spent picking parts and the number of movements. If the benefits are unclear to them, they could resist the new way of working. By explaining these benefits and why they are necessary, they will be more tolerant in accepting the new strategy.

5.6.2 Budget/Costs

The implementation of the new strategy comes with additional costs. This additional cost comes from the production of the new container used for the picking operation. As mentioned earlier, company Y has the knowledge and equipment to produce the new container. Therefore, the only production cost of this container is the raw material cost. However, since the design of the container is not yet finished, it is difficult to determine how much the production of the container will cost.

5.6.3 Risks

Section 3.3.2 discussed kitting errors, these kitting errors include wrong component, missing component, defective component, wrong quantity, and wrong position. The following sections discuss each of these kitting errors and how to prevent them or limit their risk.

5.6.3.1 Wrong Component

During the creation of the kits, there is a possibility that the picker places the wrong component in the kit. This will result in additional costs later in the process since the assembly worker who finds the error must restore it by collecting the correct component from the warehouse and returning the wrong component. To prevent this, the assembly worker must check the picking list before assembly starts. This additional control step will reduce the wrong component kitting error and thereby keeping the additional cost to restore this error to a minimum.

5.6.3.2 Missing Component

The missing component kitting error is of the same nature as the wrong component kitting error. During the creation of the kits, there is a possibility that the picker forgets to pick a component. This kind of kitting error can be prevented by the same control as discussed for the wrong component. By letting the assembly worker check the list after picking a missing component error can be identified and corrected straight away.

5.6.3.3 Defective Component

Another kitting error that might occur is that a defective component is placed in the kit. Due to kitting only the required parts are moved to the warehouse, so if one part is defective, there is no spare part in the assembly department. Therefore, the assembly worker has to go to the warehouse and pick another part to replace the defective part. However, the chance of a defective part arriving at the assembly department is relatively low. Before the parts are moved to the warehouse the paint shop workers do an extensive quality check on all the parts. Therefore, defective parts do not reach the warehouse. However, there is a possibility that a part gets damaged in transport to the warehouse and from the warehouse to the assembly department. The chance of this happening is low. When the parts are moved from the paint shop to the warehouse they are protected by styrofoam and a box pallet. The container that is used to transport parts from the warehouse to the assembly department has been designed with a low risk of damaging parts. Therefore also the risk of damaging parts during this transport is at a minimum. The quality check and current transportation methods are in place to keep the risk of damaging parts low. No further actions are needed to reduce the risk of a defective component reaching the assembly department since the risk is already low. However, if a defective part reaches the assembly department, the logistics worker or assembly worker has to pick a new part from the warehouse.

5.6.3.4 Wrong Quantity

During the picking of parts in the warehouse, the picker can pick the wrong quantity of parts. This kitting error is very similar to the missing component error regarding consequences and prevention. The wrong quantity can be too many or too few parts. In case of too many parts, the logistics or assembly worker has to move the additional parts back to the warehouse. In case of too few parts, the same situation arises as with a missing component. Therefore, a check is executed after the kit has been created to prevent the picker from picking parts in the wrong quantities from the warehouse. This check identifies if all parts are in the kit and in the correct quantities.

5.6.3.5 Wrong Position

As described in Section 3.3.2, a wrong position within the kit is a kitting error. The literature study found that the wrong position within the kit could result in additional movement to get to the desired part. However, in the design of the container free picking has been considered and applied. This results in a container from which all parts can be picked at all times without first having to move other parts. So the possibility of placing a part in the wrong position within the kit has been eliminated since the parts do not have designated locations within the kit. Therefore, this error is no longer a threat to the kitting strategy.

5.6.4 Evaluation

After implementation, it is imperative to evaluate the new situation to ensure the goal has been achieved and if there are any additional improvement points. Therefore an evaluation is incorporated, so once the plan has been implemented company Y can check if the solution has the desired results.

To ensure that the solution has the desired results, it is necessary to look at the goals of the solution. The two goals that were determined at the beginning of this research were reducing the number of movements from the warehouse to the assembly department and saving space in the assembly department.

To validate that the solution achieved the first goal it needs to be confirmed that the number of movements from the warehouse to the assembly department has been reduced. When the research started, the number of movements was 14. If the number of movements has reduced after implementing the solution it can be determined that the goal has been reached. It has been estimated that the number of movements from the warehouse to the assembly department will be around 4.

To validate if the solution achieved the second goal, it needs to be confirmed that the number of box pallets in the assembly department has been reduced. When the research started, the number of box pallets in the assembly department was on average 80. It has been estimated that the number of box pallets in the department after implementing the solution should be around 66. Since the 14 box pallets that were placed in the assembly department for the cabinet are no longer present. However, these 14 box pallets have been replaced by the new kitting containers. These are new objects that are in the assembly department, thus taking up space. Therefore, by just counting the number of box pallets, it is not entirely sure how much space is saved. The surface area of the 14 pallets (13.44 m2) and the surface area of the kitting containers should be compared to ensure space has been saved in the assembly department. The surface area of the kitting container is dependable of the design. Therefore, this is still unknown. An estimate is that it will have a surface area of 2 m^2. This is based on the measurements of cabinet X parts that are to be included in the container from Table 5.

5.7 Conclusion

This chapter compared the solutions from Chapter 4. The one kit–paint shop solution scores the best on the chosen criteria. Therefore, company Y should implement this solution to solve the bottlenecks. This solution would reduce movement by 78.57%. Upon implementing this solution to more products, the returns will increase.

However, this solution requires company Y to implement a fixed batch size. Company Y believes this reduces flexibility in the production process. If company Y is unwilling to adjust the batch sizes to match with the one kit – paint shop solution, company Y can implement the one kit – warehouse solution; this solution does not require fixed batch sizes. However, this alternative performs less on the chosen criteria and is less economical. It reduces movement by 57.14% instead of 78.57% with the other alternative. However, the reduction in space remains the same.

In terms of packaging, the vertical Minomi alternative performs best on the criteria. Therefore, this packaging method is the chosen solution for the new picking strategy. This reduces the required space by 57.14%. The space reduction is based on the case study. It reduces 14 pallets ($14m^2$) to 3 containers ($6m^2$). Upon implementing this solution to more products, the returns will increase.

The chosen solutions require an investment to create new containers. The exact price for these is hard to determine since the design is not entirely finished. Furthermore, company Y needs to consider the complications that might occur when implementing this solution. It is therefore essential to take the considerations from Section 5.6 under advisement before implementing the solutions.

6 Conclusion & Recommendations

This chapter concludes the research of this thesis. It provides a recommendation to company Y and possibilities for additional research.

6.1 Conclusion

This thesis answers the question: *“How can the packaging and picking operations of company Y be adjusted to save space and increase efficiency in the assembly department?”*.

The performance analysis of the assembly department shows that two main goals are to be achieved to solve the problem. The first was reducing the number of box pallets in the assembly department. The second was reducing the number of movements from the warehouse to the assembly department.

These two bottlenecks were used to create a strategy to achieve both goals and answer the research question. Based on the literature review and the performance analysis the strategy that was created is a kitting strategy. This kitting strategy consists of three parts, picking, production and packaging. By using the Managerial Problem Solving Method by Heerkens & van Winden (2017), multiple solutions were created that solved the research question and reached the goals of this research. After these solutions were compared, two solutions remained, from which company Y can choose depending on their preferences. The one-kit paint shop solution reduces movement the most, with 78.57%. However, this solution requires company Y to adjust its batch sizes. If this is undesirable, company Y can choose to implement the one–warehouse alternative that supports all batch sizes. However, this solution only reduces movement by 57.14%.

The container in which parts are placed has been designed so all parts can be placed in the same container. Furthermore, the vertical Minomi-concept has been used. This solution saves 57.14% of space. The space reduction is currently calculated based on the case study. It reduces 14 pallets ($14m^2$) to 3 containers ($6m^2$). Upon implementing this solution to more products, the returns will increase. This enables the vertical storage of parts within the container without using additional packaging materials. The most important feature this container provides the assembly worker with is free picking. This means that any part can be picked at any time without first having to move other parts within the container.

6.2 Recommendation for Company Y

We recommend that company Y implements the one kit – paint shop solution explained in the previous section. This solution reduces movement from the warehouse to the assembly department. In the old situation, 14 pallets had to be moved to the drop-in zone and then to the assembly location. In the new situation, only 3 containers must be moved directly from the warehouse to the assembly location. Furthermore, this solution saves space. In the old situation, 14 pallets were placed on the floor, taking up valuable workspace. With the new strategy in place, only 3 containers must be placed in the assembly department, thereby saving space. However, if company Y is unwilling to adjust the batch sizes, which is a requirement for this solution, it is also possible to chose the one kit – warehouse alternative. This solution saves the same amount of space but does not perform as well on movement reduction. Furthermore, the adjusted batch sizes are more economical based on the EOQ calculation.

6.3 Additional Research

To verify if the proposed solution in this thesis solves the problem, it is advised to evaluate the solution after implementation. Therefore, Section 5.6 incorporates an evaluation.

Furthermore, as mentioned in Section 5.6, additional research is needed to create a detailed container design. This research does incorporate the general requirements and design specifications of the container. However, a more detailed design should be created by someone who is educated about this in more detail. Such as a mechanical engineer.

7 Bibliography

Bozer, Y. A., & Mcginnis, L. F. (1992). Kitting versus line stocking: A conceptual framework and a descriptive model*. In *International Journal cf Production Economics* (Vol. 28).

Caputo, A. C., Pelagagge, P. M., & Salini, P. (2017). Modelling human errors and quality issues in kitting processes for assembly lines feeding. *Computers and Industrial Engineering*, *111*, 492–506. https://doi.org/10.1016/j.cie.2017.04.004

Fager, P., Hanson, R., Medbo, L., & Johansson, M. I. (2019). Kit preparation for mixed model assembly – Efficiency impact of the picking information system. *Computers and Industrial Engineering*, *129*, 169–178. https://doi.org/10.1016/j.cie.2019.01.034

Fager, P., Hanson, R., Medbo, L., & Johansson, M. I. (2021). Links between kit quality and kit preparation design. *International Journal of Production Research*, *59*(18), 5525–5539. https://doi.org/10.1080/00207543.2020.1785035

Fansuri, A. F. H., Rose, A. N. M., Nik Mohamed, N. M. Z., & Ahmad, H. (2017). The challenges of lean manufacturing implementation in kitting assembly. *IOP Conference Series: Materials Science and Engineering*, *257*(1). https://doi.org/10.1088/1757-899X/257/1/012069

Hanson, R. (2011). Effects of using minomi in in-plant materials supply. *Journal of Manufacturing Technology Management*, *22*(1), 90–106. https://doi.org/10.1108/17410381111099824

Hanson, R., & Medbo, L. (2012). Kitting and time efficiency in manual assembly. *International Journal of Production Research*, *50*(4), 1115–1125. https://doi.org/10.1080/00207543.2011.555786

Hanson, R., & Medbo, L. (2019). Man-hour efficiency of manual kit preparation in the materials supply to mass-customised assembly. *International Journal of Production Research*, *57*(11), 3735–3747. https://doi.org/10.1080/00207543.2019.1566653

Heerkens, H., & van Winden, A. (2017). *Solving Managerial Problems Systematically 1e edition*.

Loboka, S. (2022). *Improving the efficiency of the assembly department*.

Material Handling Wholesaler. (2015, August 21). *Minomi systems address the lean movement of material with less waste*. https://www.mhwmag.com/products/minomi-systems-address-the-lean-movement-of-material-with-less-waste/

Regel-Rosocka, M. (2010). A review on methods of regeneration of spent pickling solutions from steel processing. In *Journal of Hazardous Materials* (Vol. 177, Issues 1–3, pp. 57–69). https://doi.org/10.1016/j.jhazmat.2009.12.043

Richards, & Gwynne. (2014). *Warehouse Management: A complete guide to improving efficiency and minimizing costs in the modern warehouse* (Second Edition). Kogan Page Limited.

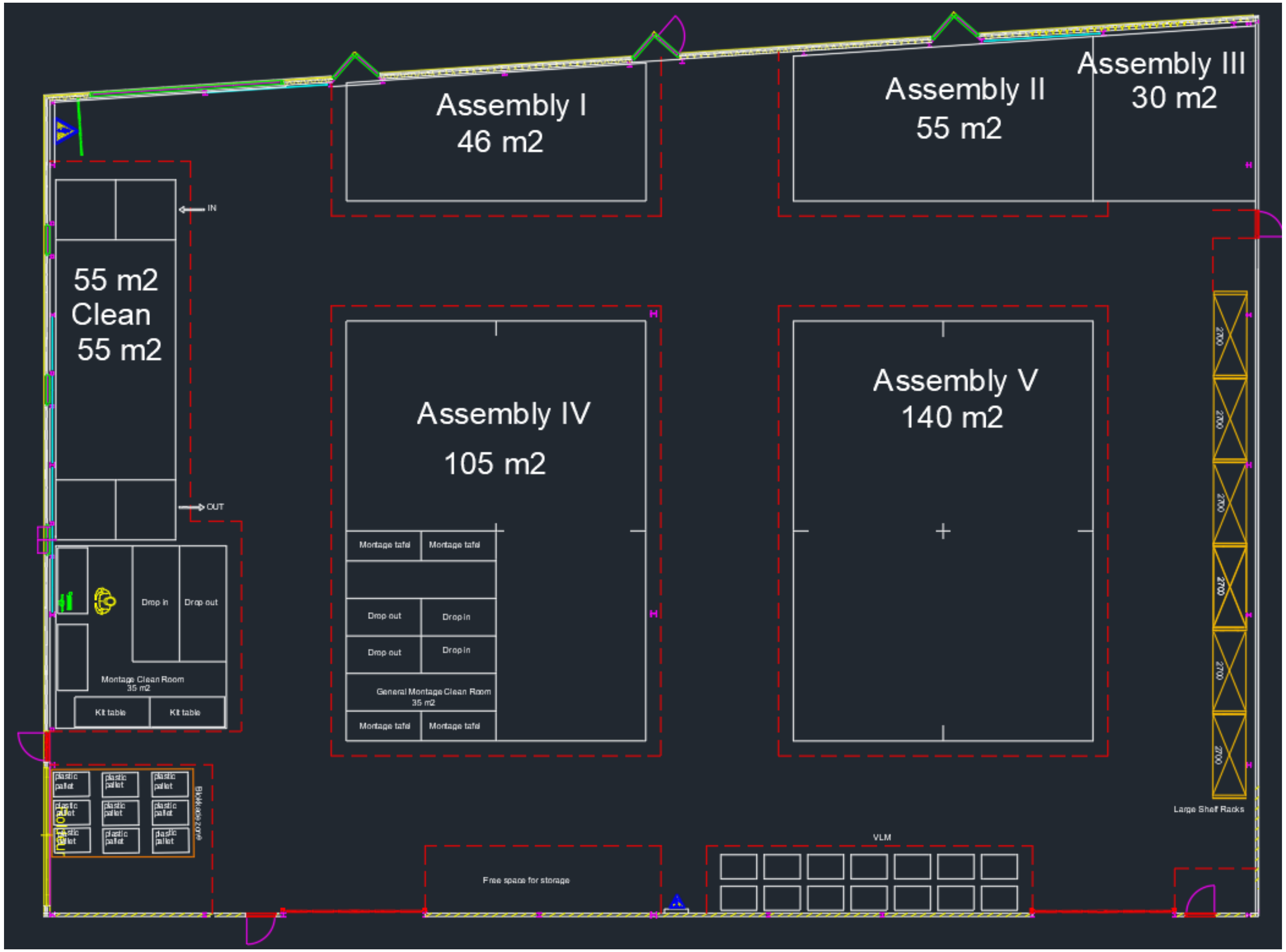
Slack, N., Jones, A. B., & Johnston, R. (2016). *Operations Management* (Eighth Edition). Pearson. www.pearson.com/uk

Theisens, H. C., & Hampsink, F. (2017). *Lean six sigma green belt : mindset, skill set & tool set*.

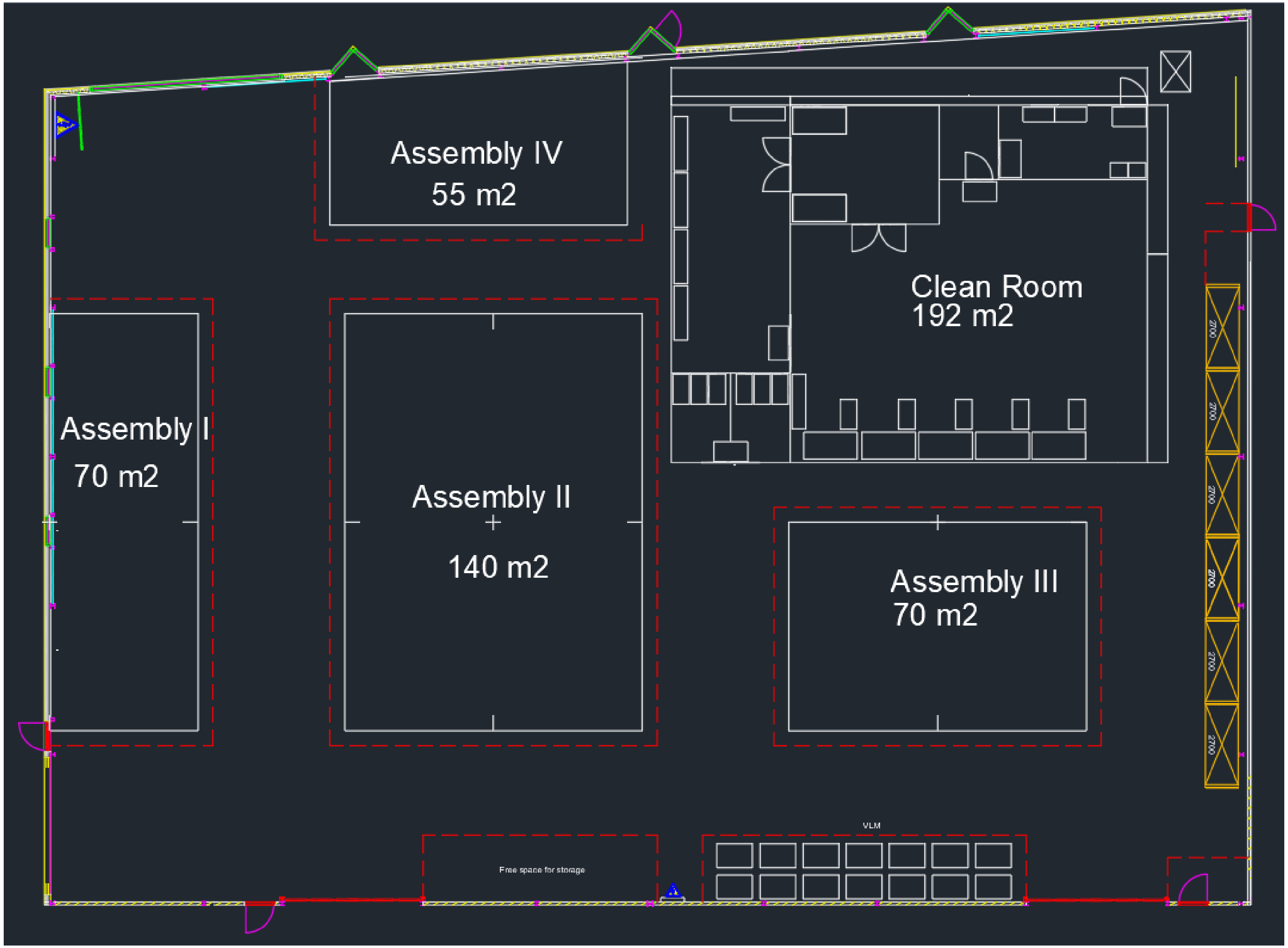
Winston, W. L. (2004). *Operations Research: Applications and Algorithms* (fourth).

8 Appendices

Appendix A – Current Layout Assembly Department



Appendix B – Future Layout of the Assembly Department



Appendix C – Pictures of Assembly Department


SCANIA