Improving production Logistics

26-1-2023

Jilmer Russchen | University of Twente | Eternit Goor

Bachelor Thesis industrial engineering and management

Improving production logistics

Author

Jilmer Russchen

j.russchen@student.utwente.nl

Supervisor Etex
D. Janssens (Dries)
Supply chain manager
Benelux

Eternit Goor
Haven 12
7471 LV
Goor
The Netherlands

Supervisors University
DR.IR J.M.J. Schutten (Marco)
DR. B. Alves Beirigo (Breno)

University of Twente
Drienerlolaan 5
7522 NB
Enschede
The Netherlands

Foreword

As the last assignment before I graduate from my IEM study, I am thrilled to present this thesis on reducing handling times at Eternit B.V.

First and foremost, I would like to express my gratitude to my parents, who have always supported and encouraged me in my academic pursuits. My mother has always been there to listen when I struggled and gave me emotional support. At the same time, my father, the plant manager at Eternit B.V., provided valuable guidance and insights during the research and writing of this thesis.

I would also like to thank my friends, who have always been there for me, providing support and encouragement during the challenging times. Without their support, I would not have been able to complete this thesis.

Additionally, I am grateful to my company supervisor, Dries Janssens, for allowing me to conduct this study at Eternit B.V. and for his support throughout the process. My university supervisor, Marco Schutten, also deserves a special mention for his guidance and mentorship throughout my thesis.

Finally, I thank my second supervisor, Breno Alves Beirigo, for his support and guidance.

I am confident that the findings and recommendations presented in this thesis will benefit Eternit and improve its production process.

Once again, I would like to extend my sincere thanks to my parents, Dries Janssens, Marco Schutten, Breno Alves Beirigo, and my friends for their support and guidance. Working on this thesis has been a pleasure and a privilege. I am grateful for the opportunity to contribute to reducing handling times in Eternit's production process.

Thank you,

Jilmer Russchen

Enschede, January 2023

Management summary

This thesis aims to reduce handling times at Eternit B.V. in Goor. This company produces corrugated sheets and fittings for roofing. Fittings are specialized pieces used to waterproof a roof fully. By handling times, we mean the time needed to transport parts or materials to or from a work area. High handling times can lead to increased costs, decreased efficiency, and reduced productivity. A problem identification process was conducted at Eternit B.V. to address these issues to identify the root cause of the high handling times. The research identifies four core problems: traffic bottlenecks, one-way traffic, the old way of working, and the outdated layout of warehouses. The research question for this thesis is *"What changes to production logistics does Eternit have to make to decrease handling times?"*

The thesis includes a literature review of various management strategies and tools used to reduce handling times. The literature review includes Lean, a management strategy focused on waste reduction, value enhancement, and people involvement. In Lean, eight types of waste can be distinguished, and various methods are used to analyze business processes, including spaghetti diagrams, value stream mapping, and time value mapping. The Theory of Constraints is another management strategy discussed in the literature review. It aims to eliminate waste in the production process and improve bottlenecks by following six steps.

In addition to these management strategies, the literature review includes data on automated guided vehicles (AGVs) and idea generation. AGVs are autonomous vehicles that move products from one location to another, reducing human involvement in transportation and increasing efficiency. Idea generation is essential when trying to come up with solutions and criteria. The best ideas are selected through brainstorming using the hits and hot spots method or an evaluation matrix.

We analyzed the current situation at Eternit B.V. using spaghetti diagrams, value stream maps, and time value maps. These tools showed us that much traffic occurs around the G4 and machinecoating areas and that 68.5% of the time is non-value-adding for sheets and 11.3% for fittings. Transportation is the main cause of wasted time. The value stream maps also indicated that creating a pallet with sheets or fittings is very efficient, with almost no waiting times that can be eliminated.

To achieve optimal handling times, we need to minimize transportation. To do this, we propose three solutions. The first solution is implementing one or more automated guided vehicles (AGVs) at strategic locations within the factory. This will increase efficiency by allowing for faster transportation of products, particularly during non-operational hours, while ensuring safety through the implementation of appropriate measures. The projected payback period for this solution is 2.6 years, which meets the company's criterion. The second solution is to change the one-way doors after 17:00. This will reduce handling time per pallet by 100 seconds. Changing the one-way doors after 17:00 can be made safe through cameras, laser scanners, or signs. The third solution is to optimize the layout of the factory warehouse to improve material flow and decrease handling times. This involves positioning the most frequently sold products closer to the G4 line or exits while considering limitations such as space constraints, stacking limits, and the company's first-in-first-out methodology.

We recommend that Eternit prioritize implementing the most important solution, the AGV system, first. This solution is the most time-consuming and expensive. However, it is essential to address the current issues in the factory. However, this implementation can be carried out concurrently with the other solutions as an external company will primarily handle it. After implementing the AGV system, we suggest implementing less costly and easier solutions such as changing the one-way doors after 17:00, which is a simple and inexpensive solution, and changing the layout of the factory warehouse, which may take longer but is still relatively affordable. By implementing multiple solutions simultaneously, Eternit can save time and quickly address the current issues within the factory.

List of figures

List of tables

Table of contents

1 Introduction

This chapter introduces the company Eternit B.V. Goor (Eternit after this) and its problems. The chapter explains knowledge questions, demarcation, and problem-solving approaches. Chapter 1 has the following structure:

Section 1.1 Introduces Eternit and its products.

Section 1.2 Gives the problem definition and explains where the problem occurs.

Section 1.3 Describes the action and core problem the company faces, as well as the knowledge questions formulated to solve this problem.

Section 1.4 Gives a stakeholder analysis.

Section 1.5 Explains the demarcation.

Section 1.6 Gives the structure of the report.

1.1 About Eternit

The research is conducted at Eternit B.V. (Eternit after this) in Goor. Eternit is a company within the Etex group that specializes in producing corrugated roofing sheets. Currently, 111 employees are working at Eternit, producing around 10 million m^2 of corrugated sheets yearly. Eternit sells these corrugated sheets to both the Dutch and the European market. Over 50% is sold to the European market, mainly to the agricultural sector.

Figure 1: Corrugated sheet

Etex is a multinational industrial group with its headquarters based in Belgium. The company offers various building materials, including corrugated roofing sheets and conduit insulation. Currently, the group has companies located in 42 countries with a combined total of more than 15,000 employees.

Eternit mostly creates corrugated sheets. These corrugated sheets are made from fibre cement on an extensive automated production line, as shown in Figure 1. Eternit also creates fittings in the hand moulding. These fittings primarily connect corrugated sheets to ensure a roof is completely waterproof, as shown in Figure 2. The company has five different departments, each with its specific tasks. Table 1 lists these departments and their allocated tasks.

Department	Task
G4	The G4 department ensures that the G4 line keeps working. The G4 line is an extensive automated production line where Eternit creates most of its products.
Handcoating & hand moulding	In this department, specialized roofing pieces are created and coated mostly by hand.
Logistics	This department takes care of all transportation within the warehouses and the factory. This department ensures the timely delivery of all orders.
Machinecoating	This department coats all corrugated sheets that the handmoulding department does not create.
Maintenance	This department takes care of repairing all the defective machine parts and forklift components.

Table 1:Departments at Eternit

The factory has two different processes. One process is to create corrugated sheets, and the other is to create fittings. These two processes contain quite a few steps and are very different. A1 shows these two processes.

1.2 Problem definition

Eternit uses manned forklifts to handle internal transport. They move pallets from one location to another twice a day, from 6:00 to 14:00 and from 7:30 to 16:00. Most forklift traffic happens between the G4 and the machine coating line. However, the lack of a transportation policy causes inefficiencies and unnecessary steps for forklift drivers. To solve this problem, the research aims to find an optimal way of working that minimizes handling times. Handling times refer to the time it takes to transport parts or materials to or from a work area. Specifically, this research will measure the time it takes to move a pallet from the end of the G4 line to the logistics department's warehouse. The research will also examine the various processes that the pallet goes through, including transportation and stacking. The current handling times are unknown, so the research will measure them to identify solutions and improve the current situation. Additionally, changes in the warehouse layout have created traffic bottlenecks and inefficiencies, resulting in higher handling times.

Eternit mentioned that they want to decrease handling times and improve their logistics department. One potential solution they want to look into is the acquisition of an Automated Guided Vehicle, or AGV in short. An AGV is an autonomous vehicle capable of moving pallets from one location to another without needing to be controlled by an operator. Section 2.4 better explains the AGV concept. Because of this, an AGV could transport products early in the morning or late at night. Currently, there are no forklift drivers in the early morning during the night, so no transport occurs during these times. Sections 2.4 and 4.3.1 explain and discuss the AGV idea. Eternit expects growth in the coming years, so they want the production logistics to be future-proof, streamlined, and more efficient. That is the main focus of this project.

1.3 Action problem and knowledge questions

This section goes over the action problem, the core problem, and the knowledge questions created to solve this action problem.

1.3.1 Action problem

The Managerial problem-solving method (Heerkens, 2012) states that a problem exists when there is a discrepancy between the norm and reality. Eternit faces a similar problem. To solve this problem, Eternit needs to bring reality closer to the norm, in this case, acceptable handling times. The current reality is that handling times within the factory are too high. To address this, Eternit aims to decrease handling times to a more desirable level by solving the action problem. Therefore, the action problem is:

"Handling times within the factory are too high."

1.3.2 Core problem

To find the core problem, we trace back all the problems that lead to the action problem. We use a problem cluster to trace back all the problems that lead to the action problem. Figure 3 shows this problem cluster. After backtracking, multiple problems cause the action problem to occur. The yellow indicated boxes show core problems that can be influenced and potentially solved by researching and finding solutions. These problems are the following.

Traffic bottlenecks Within the factory, there are a few points where traffic gets stuck or where it is hectic. These bottlenecks can cause forklifts to have to wait for each other. This waiting adds to the handling times.

One-way traffic The second problem is that there are doors that only allow for one-way traffic. There is a door in the factory where products come in from the outside. This door, however, is only meant for one-way traffic (from the outside to the inside of the factory). Moving products outside forces the forklift drivers to take a different route, which is longer, leading to higher handling times.

The old way of working The old way of working causes forklift drivers to drive according to an outdated way of working. Eternit's outdated way of working causes forklift drivers to perform unnecessary steps or waste time due to stagnation.

The warehouse layout is outdated Eternit's factory produces a wide range of products that require large pallet sizes and significant storage space. However, the current warehouse layout is outdated and not optimized for efficiency. The corrugated sheets are stored randomly within the factory based on the production schedule, leading to product storage inefficiency. For example, products produced earlier in the week might be placed close to the G4, even though that might not be the optimal location for them. This results in longer handling times and increased operational costs. An optimal layout, where products are stored in fixed locations, would significantly improve efficiency and reduce handling times

Next to these yellow boxes, there is one orange box. This box shows a problem that our research cannot influence. The forklift speeds are low because of health and safety concerns. In consultation with the health and safety manager at Eternit, we conclude that these speeds cannot be changed.
The other problems following these core problems are all self-explanatory. The one that might cause some confusion is the 'A lot of unnecessary steps are performed' problem. The old way of working causes products to be placed in random locations within the factory and picked up by another forklift driver. This process could also be done in one movement, decreasing the handling times.

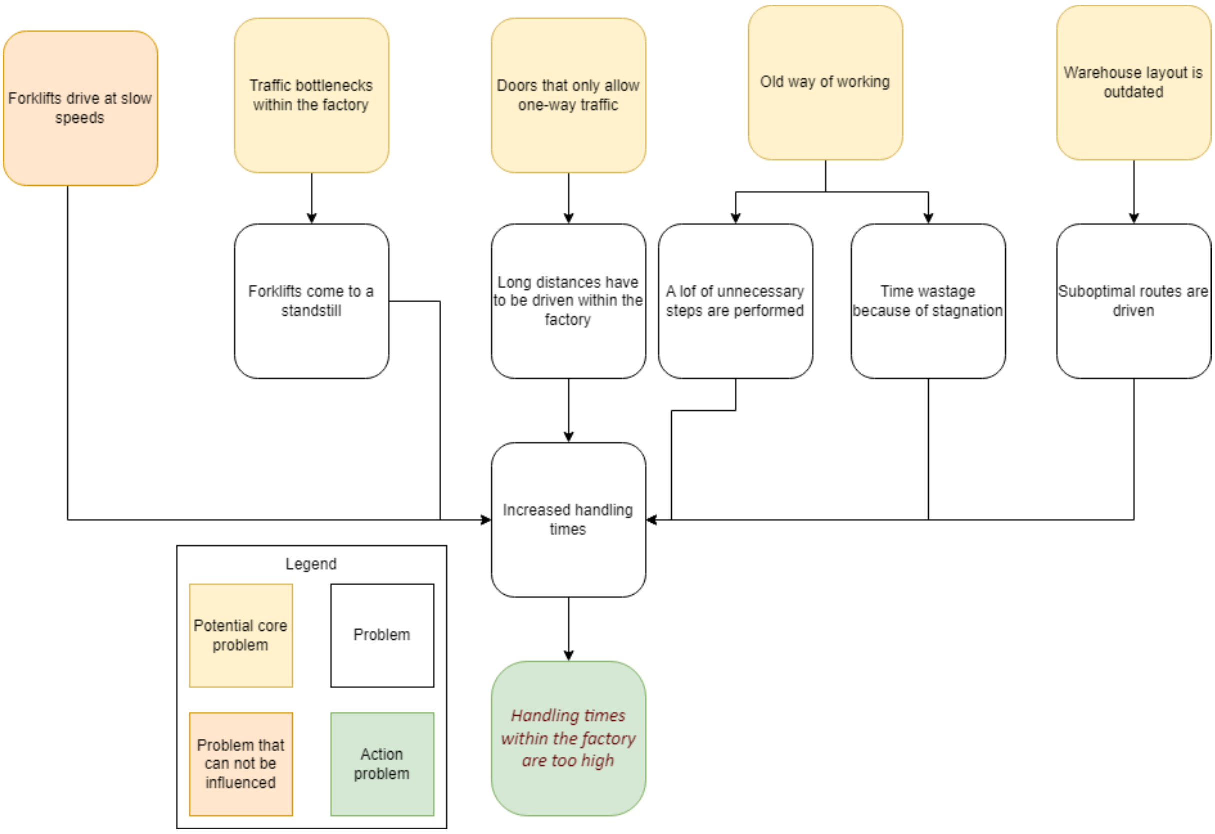

Figure 3: Problem cluster

1.3.3 Knowledge questions

We formulate knowledge questions to divide our research question into easier-to-tackle questions and answer our research question. The research question for this thesis is*: "What changes to production logistics does Eternit have to make to decrease handling times?"* To answer the research question, we formulate the following knowledge questions:

1. *What literature aids with analyzing and improving the current situation?*

This knowledge question answers what literature is used to solve the problem. Literature regarding Lean, problem-solving, idea generation and AGVs is searched and explained.

2. *What is the current situation within the factory?*

It is crucial to understand the current situation. Knowledge question 2 gives more insight into the current situation.

2.1 *What are the current paths the products take?*

We first need to know the products' path within the factory to see where the high handling times come from. Finding the handling times is done by first finding methods to analyze production processes. After finding the correct method(s), it is applied to depict the actual situation at Eternit. By answering this question, we gain more insight into the transportation done within the factory. It could potentially identify where the bottlenecks are.

2.2 What are the current handling times?

Now that we know the routes that the products take, we can start to take a look at handling times. The handling times are measured by performing observations and conducting interviews. After researching all the handling times, value stream maps and time value maps are created to find where potential bottlenecks are located.

3. *How can the handling times be decreased?*

After discovering the problems and mapping all the processes, it is time to research how the handling times can decrease. This is done by performing desk research and conducting interviews with stakeholders. The knowledge gained from knowledge question 1 helps with this. Finishing this knowledge question provides multiple solutions to solve the problem. As mentioned in Section 1.2, the AGV idea is also considered during this research question. This is because An AGV could be a possible solution for decreasing the handling times.

4. *What is the best solution?*

After proposing multiple solutions, choosing the best one(s) together with the stakeholders is essential. The decision on the best solution(s) will be made through conducting interviews. These interviews will serve to gain a deeper understanding of the key elements of each solution. With this knowledge, it is more likely that the appropriate solution(s) is recommended.

5. *How to implement the solution(s)?*

After determining the best solution(s), it is essential to devise an implementation plan to ensure that the solutions are implemented and benefit the company. Failure to develop an implementation plan may render the solutions ineffective. Desk research answers this knowledge question.

1.4 Stakeholder analysis

To effectively perform research, it is important to identify and understand the stakeholders involved and interested in the project. To achieve this, we conduct a stakeholder analysis, which clearly illustrates the stakeholders and their level of interest and influence on the research project. In this case, nearly all employees at Eternit are related to the problem in some way. Since there are approximately 110 individuals, we divide them into groups and create a table to gain a clear overview of each stakeholder. The Etex group, as Eternit's parent company, holds the most significant influence, followed by Eternit BV.

Additionally, various groups of individuals have different roles and levels of influence. A diagram in A2 illustrates this information. We do not consider external stakeholders as they do not impact the research or potential solutions.

1.5 Demarcation

The research for this thesis focuses on internal transport within the factory. We limit our scope of study to the internal operations of Eternit as the company reported no issues with transportation outside the factory. An analysis of the entire company is not feasible within the constraints of this research project.

Regarding data collection, we interview and conduct brainstorming sessions with the most relevant stakeholders, such as the plant and supply chain managers, to gather insights and perspectives from those most impacted by the handling process. We do not consider other employees as they have little to no influence on the outcome of our research. The essential stakeholders are described more clearly in Section 1.4.

1.6 Report structure

The research answers multiple knowledge questions to find a solution to the action problem. The chapters are structured according to the sequence of the knowledge questions.

Chapter 2 answers the first knowledge question. Chapter 2 contains literature concerning Lean, problem-solving, idea generation, and AGVs.

Chapter 3 answers the second research question by presenting the observations made at Eternit, illustrated through spaghetti diagrams, value stream maps, and time value maps. These diagrams and maps were created by carefully observing the forklift movements within the factory. The chapter provides a thorough depiction of the terrain, all forklift paths, and handling times

Chapter 4 addresses the third and fourth knowledge questions by formulating potential solutions to reduce handling times. These solutions are thoroughly examined through desk research and interviews. The fourth knowledge question is answered through interviews and brainstorming sessions by identifying the most suitable solution(s). The best solution(s) is selected following this process.

Chapter 5 answers the fifth and final knowledge question. It contains a plan for Eternit to implement the previously chosen solutions.

Chapter 6 gives the final conclusions, discussions, and recommendations for Eternit. Chapter 6 is the concluding chapter of this report.

2 Literature

This chapter describes the literature that aids in finding and solving the problem. The chapter consists of four parts: Lean management literature, the theory of constraints, idea-generation literature, and the automated guided vehicle (AGV) literature. Chapter 2 consists of the following Sections:

Section 2.1 Describes the Lean management literature

Section 2.2 Describes the theory of constraints

Section 2.3 Describes the idea-generation literature

Section 2.4 Gives the reader information about Automated Guided Vehicles

Section 2.5 Concludes the chapter

2.1 Lean management

To improve production processes, certain Lean theories and strategies are implemented. Lean has become one of the most widely adopted management approaches, focusing on "doing more with less" and continuous improvement in three main areas (Bicheno & Holweg, 2016).

- Waste reduction
- Value enhancement
- People involvement

In Lean, there is no end goal because every process has room for improvement. Lean is not easy; It requires long-term consistency. Lean uses various techniques and tools to accomplish the reduction of waste. This section mentions some of these tools.

2.1.1 The eight wastes

There are eight types of waste (Lean in De Praktijk, 2019). Figure 4 shows these wastes. It is crucial to understand and distinguish all eight different types of waste. All employees of a company must know these types of waste so that they can help improve processes. The eight types of waste are the following. The wastes most relevant to our research are in bold.

1. ***Transportation***
   Transportation between two locations is wasteful because it does not add value to the customer. It is therefore important to minimize transportation costs.
2. *Inventory*
   Keeping finished products or raw materials in inventory is a type of waste. Inventory only causes stagnation and does not add any value to the product.
3. ***Motion***
   Motion refers to all unnecessary human movement for completing an action. This is often the result of the workplace layout not being optimal. Motion does not add any value, which is why it should be minimized.
4. ***Waiting***

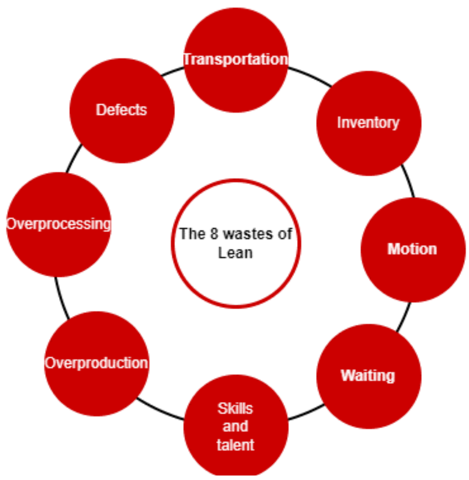

Figure 4: The 8 wastes of Lean (Source: processexcellentnetwork)

We refer to the stagnation of products as waiting. Waiting happens when we wait for the next step to begin. This can happen when a machine breaks down, or an employee has to wait for input from another employee, for example. Waiting is a waste because the handling time of the product increases.

5. *Overproduction*

Overproduction means creating more products than needed. Overproduction is mainly caused by producing big batches. Overproduction often causes other types of waste, like inventory or waiting. This is why it is one of the most essential wastes to keep to a minimum.

6. *Overprocessing*

When more value is added to the product than a customer requires, this is called overprocessing. A customer pays for a specific product. When unnecessary processing is added to this product, it could cost valuable money and time; this is why overprocessing is a waste.

7. *Defects*

Products that are incomplete or do not meet customer requirements are wasteful, as they often need to be reproduced or repaired. Replacing a product costs time and money.

8. *Skills and talent*

Failure to fully utilize employees' abilities and skills is wasteful, as it can lead to wasted potential. This type of waste can be reduced through employee training and development.

2.1.2 Methods to identify wastes

This research uses three methods to identify waste: ' spaghetti diagrams,' 'value stream mapping,' and 'time value mapping.' These methods are commonly used in Lean to map processes and find potential wastes.

For our research, a spaghetti diagram is an excellent way of analyzing where the most traffic in the factory takes place. It also shows all possible paths that products cover. Value stream mapping is another valuable tool because it shows where waiting occurs and how effective the production process is. Time value mapping is an effective method for identifying and eliminating bottlenecks and wastes in production processes. By utilizing these tools, we can ensure that the current processes at Eternit are accurately mapped and timed, enabling us to conduct thorough research and make informed decisions.

2.1.2.1 Spaghetti diagram

A spaghetti diagram is a tool used to show distances and paths within a workplace. This is done by showing all routes and movements that employees or products take within the workplace. It clearly shows how the products move and how often a specific movement is performed (Pyzdek, 2021).

When creating a spaghetti diagram, creating a simplified ground plan is essential to have a clear overview of the analyzed workplace. Next, draw all movements with simple lines from the starting point to the endpoint, often using various colours to differentiate people, products, or timeframes. It is crucial not to leave out any movements, even if the spaghetti diagram becomes messy. Figure 5 illustrates an example of a spaghetti diagram with multiple people.

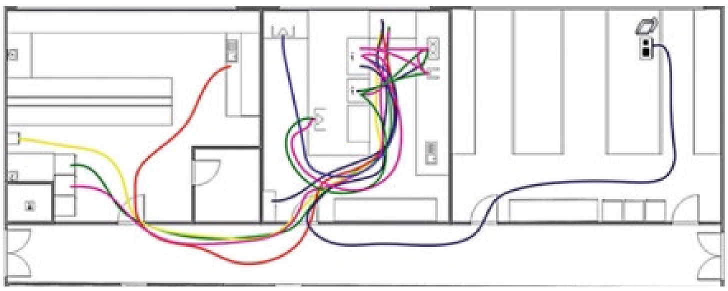

Figure 5: Spaghetti diagram example (The lean healthcare handbook, 2011)

A spaghetti diagram by itself is not a method to optimize a process. It only shows the current state. However, a spaghetti diagram could show potential wastes in a process. With these wastes made clear, improvements can be made to increase production efficiency.

2.1.2.2 Value stream mapping

Value stream mapping is a method to visualize business processes. Value stream mapping aims to minimize waste in a production process and keep lead times as low as possible (Theisens, 2018). Value stream mapping is a tool used in the Lean methodology that involves creating a visual representation of all the activities involved in a process, from start to finish. It applies to almost all value chains and helps understand and improve manufacturing processes. A value stream map shows the activities required to produce a product. The purpose of a value stream map is to see the difference between various activities. Three activities have to be distinguished (Zahrotun & Taufiq, 2018).

- ❖ Activities that do not contribute value to the final product or service (non-value-added or NVA activities) are considered waste and should be minimized or eliminated.
- ❖ Activities that do not add value but can also not be eliminated(necessary non-value added or NNVA activities). An example of this can be the time it takes for a product to dry.
- ❖ Activities that do provide value (Value added or VA activities).

The value stream mapping process has four distinct stages, as Theisens (2018) outlined.

1. *Define product family*
   During the first step, the scope of the value stream map and the process that is researched is defined. Every step and activity has to be considered. The start- and ending points also have to be made clear.
2. *Construct a current state map*
   The second step consists of creating a value stream map of the current situation. There are nine steps to creating a relevant map. These steps are the following.
   Step 1 – Map customer demand.
   Step 2 – Map production time.
   Step 3 – Map process flow and inventory.
   Step 4 – Add material flow between processes (Push and Pull).
   Step 5 – Add data boxes with current state information
   Step 6 – Add information flows
   Step 7 – Add flows for ‘raw components’ and ‘finished goods.’
   Step 8 – Add a timeline with queue time and cycle time.
   Step 9 – Determine the value-added time
3. *Future state map*
   The current state map is used to construct a future state map. A future state map is a value stream map that depicts the ideal situation of the process. A future stream map is created behind a desk and does not depict reality(yet). The future stream map generates solutions and improvements to optimize the production process.
4. *Define the work plan and implementation*

After creating a Current state map and a Future state map, an implementation plan can be made. This plan contains methods and instructions to go from the current state to the future state. This is described in a work plan. This work plan has to describe what has to happen, who has to do what, and what is needed. This leads to a successful implementation.

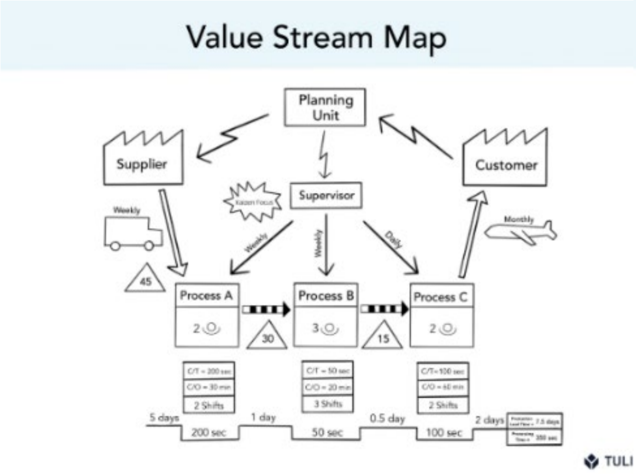

Figure 6: Value stream map example (Tulip.co, 2021)

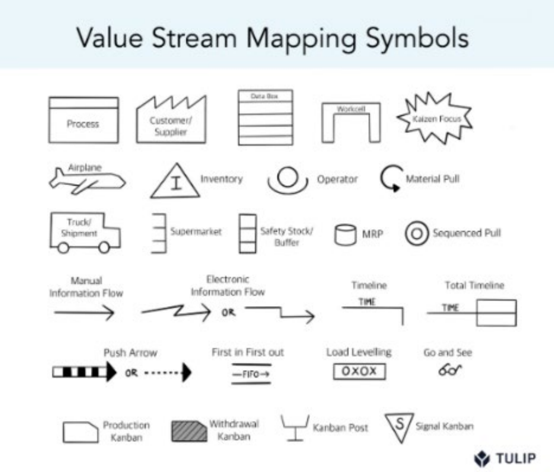

Figure 7: Value stream mapping symbols (Tulip.co, 2021)

Figure 6 illustrates an example of a value stream map, which displays all the processes and their cycle times, processing times, inventory levels, and waiting/downtimes. Figure 7 presents the symbols and definitions used in value stream maps.

2.1.2.3 Time value mapping

A time value map shows which parts of the process are value-added time and which parts are (necessary) non-value-added time. It focuses on what actions add value for the customers and what actions do not. Time value mapping is another Lean tool to identify and possibly eliminate waste within a process. Time value mapping is a tool that focuses on identifying and reducing the amount of time wasted from the beginning of a process until the final product or service is delivered to the customer. When creating a time value map, all actions have to be timed. After all actions are timed, a time value map can be created. Figure 8 shows an example of a time value map.

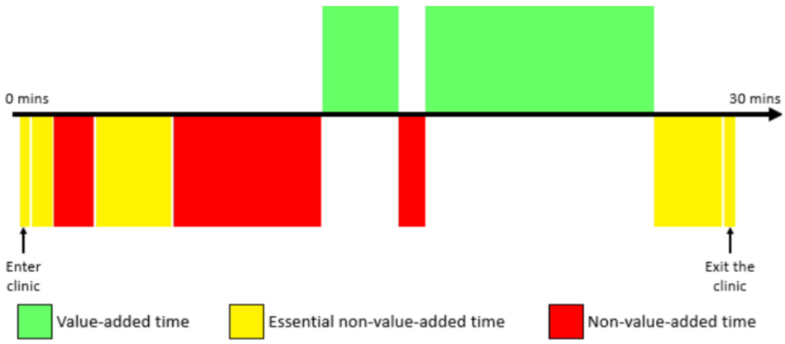

Figure 6: Time value map example (Continuous Improvement Toolkit, 2018)

In order to create a time value map, it is necessary to undertake a series of steps. The first step is to draw the process timeline. The second step is to specify the start and end times and the cycle and queue times. The third step is to draw the bars, with value-added time represented by a green bar above the timeline and (necessary) non-value-added time represented by yellow and red bars below the timeline. Through this process, it becomes possible to identify possible wastes and actions that can be eliminated. Finally, projects can be initiated to eliminate the detected wastes.

2.2 Theory of constraints

The Theory of Constraints is a method for optimizing production processes (Goldratt, 1990). The theory of constraints focuses on reducing or eliminating constraints within a production process. Goldratt states that every production process has a reduced outcome due to constraints. These constraints will affect the outcome of the entire system. Goldratt mentions that every company has financial profit as its primary goal and that the constraints restrict the company from achieving as much financial profit as possible. These constraints or bottlenecks create a ceiling for the capacity of the system. Most of these bottlenecks can be fixed with a limited amount of resources. Limited resources mean that not all bottlenecks require a significant investment to be fixed. Because of this, companies can achieve much more profit with only a little investment. Goldratt states that an hour won on a bottleneck is an hour won in the whole system, and an hour won on a non-bottleneck is wasted effort.

Within the theory of constraints (or TOC in short), the focus is not on one single process or the production rate of a single product. Instead, it focuses on the throughput of the system as a whole. According to Goldratt, a good throughput of the entire production process is only possible if all processes collaborate and communicate well. So, to optimize the production process, it is essential to identify and eliminate the bottlenecks. Elimination is done in the following five steps.

1) *Identify the system's constraints*

Identify the bottleneck or limiting factor in the production process through observations and prioritize the identified constraints based on their impact on the overall efficiency.

2) *Decide how to exploit the system's constraints*

Searching is the most effective way to exploit a constraint in this phase. Exploiting means utilizing the constraint at 100%. By exploiting a constraint, the throughput rate should increase. This increase in throughput should be achieved by only using the current resources that are available within the organization. The TOC aims to use current resources more efficiently. Suppose at one point in this phase, it is evident that the constraint cannot be removed with the current resources. In that case, the process should start at phase 1 with another constraint.

3) *Subordinate everything else to the above decision*

In this phase, the company must subordinate every other step within the process. This is important because the constraint determines the throughput rate of the whole process. The company must prioritize and focus on improving the identified significant bottleneck before attempting to improve any other bottlenecks in the process.

4) *Elevate the system's constraints*

This step is only performed if steps 2 and 3 do not eliminate the constraint. This step increases the capacity of the constraint by adding new resources. These resources could be an investment to buy a new machine, for example.

5) *If a constraint has been broken in the previous steps, go back to step 1.*

If another bottleneck appears during the improvement process, go back to step 1 to start improving the throughput of this new constraint. This is a continuous process until all the bottlenecks have been removed.

6) *Repeat the process*

The TOC process should be repeated regularly to ensure the system is continually optimized.

This focus, according to Goldratt, will lead to the best result for the company.

2.3 Idea generation techniques

This section describes techniques used for generating ideas. These techniques can aid in identifying possible solutions and constraints and criteria to guide the solution-finding process. Through research, we discovered the following literature.

According to Treffinger, Isaksen, and Dorval (2006), the book "Creative Problem Solving" outlines methods for approaching problem-solving in a creative manner. The authors highlight the importance of maintaining an open mindset when considering potential solutions and provide four guidelines for generating options:

- *'Defer judgment'* Evaluating ideas too quickly is the biggest pitfall in creative thinking. The best thing to do in creative problem-solving is to let ideas flow and save the evaluation and critical thinking for a later stage.
- *'Strive for quantity'* When there are a lot of generated ideas, the chances of having practical ideas are more significant, so it is necessary to strive for quantity.
- *'Freewheeling'* no idea must go to waste because someone thinks it is weird or invalid. Allow the respondents to be playful and strive for authenticity.
- *'Seek combinations'* One idea often leads to another; creative problem-solving also uses this concept. Allow everyone and others to connect ideas to build new ones.

After generating options, the next step is focusing options. Focusing options means finding the best ideas generated and eliminating the unusable ones. When doing this, it is required to analyze every idea constructively. This means not just throwing away an idea when it seems to be poor but instead looking at ways that the idea can still be used or improved. It is also essential to be deliberate when choosing ideas. This means knowing what tools or strategies must be used when evaluating ideas.

There are five ways to generate options and five ways to focus options. The most useful for this research is 'brainstorming' for generating options, 'hits and hot spots,' and 'evaluation matrix' for focusing options.

Brainstorming is a method to generate a lot of (sometimes unusual) ideas. Brainstorming works by putting a few people in a room with one navigator. First, the navigator explains the idea for which options have to be generated. Then, everyone in the room can freely speak their minds and come up with as many options as possible. The four guidelines for generating options mentioned at the beginning of this chapter are also significant for brainstorming since critique and not valuing quantity could ruin a brainstorming session.

Hits and hot spots selects the best options by selecting promising possibilities and then clustering and organizing them in meaningful ways. This method is referred to as finding hot spots.

An evaluation matrix is a tool that compares ideas against a set of criteria by placing them on separate axes. By evaluating each idea against the criteria, the matrix reveals how well each criterion applies to each idea. After eliminating ideas through the hits and hot spots selection method, the evaluation matrix is applied as an additional tool to ensure sufficient options are generated during creative problem-solving sessions with stakeholders.

2.4 Automated guided vehicles

An AGV is a fully autonomous robot capable of moving pallets or products from location A to location B. The market for AGVs is growing rapidly, and it is very dynamic. All around the world, AGVs have started to take over manual labour. There are many different types of AGV models that can fit most companies' needs. An AGV system consists of three main components. These components are the vehicle, the guidance path system, and the floor control management system (Kumar, 2016).

Vehicle

The vehicle is the central unit of the AGV. The vehicle is the part that transports the actual products. It is designed to fit the company's needs. There are three categories of vehicles.

-Pallet truck, this vehicle is used to move palletized loads along a predetermined route.

-Driverless train, this vehicle moves carts with products from one location to another.

-Unit load carrier, this vehicle moves products from one location to another.

Figure 9 shows three examples of AGV vehicles. They are the pallet truck, the unit load carrier, and the driverless train from left to right.

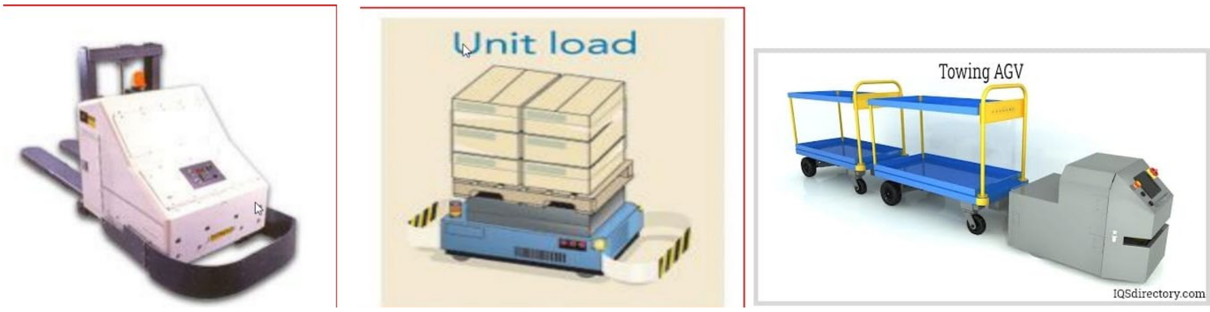

Figure 7: AGV vehicle examples(Kumar, 2016)

Guidance path system

The guidance path system is a method with which the vehicle is controlled to follow pathways. The vehicle uses the guided path system to choose a programmed path. It uses real-life measurements and compares them to programmed values to choose and follow the correct paths. Within our research, we only look at the inside of the factory. This means that methods used to guide an AGV outside are not considered. There are multiple guidance path systems. The most commonly used ones are the following. (Asaprental, 2021).

1. *Landmark based navigation*

This technique utilizes the identification and recognition of distinct features or objects (so-called 'landmarks') in the area where the vehicle drives. Either embedded guided wire or taped systems do this. Embedded guided wires are wires below the floor that emit a low-frequency signal between 1-15 kHz to the vehicle. Figure 10 shows this. These signals allow the vehicle to follow a predetermined path. The frequencies can change when the vehicle has to make a specific turn. The guided tape

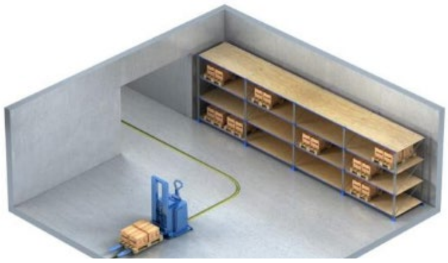

Figure 8: Landmark based navigation (Asaprental, 2021)

system is a line drawn on the floor for the AGV to follow. The vehicle can trace this line by using sensors.

2. *Vision-based system*

The vision-based system is another guidance technology for AGVs. It operates without a previously defined pathway. It uses cameras and sensors to locate its position. The control system determines the movements. There are various methods for using vision-based systems. The most popular one is laser navigation. The AGV comes with a laser scanner mounted on top of the vehicle. It scans the area for reflectors. c Using the reflectors, the AGV can determine its position. Next to this, there is contour navigation, as depicted in Figure 11. Contour navigation uses a 2d laser scanner to measure and learn the environment. Then it uses measurement learning to correct the map and achieve contour navigation. Other methods include but are not limited to natural feature navigation or autonomous navigation.

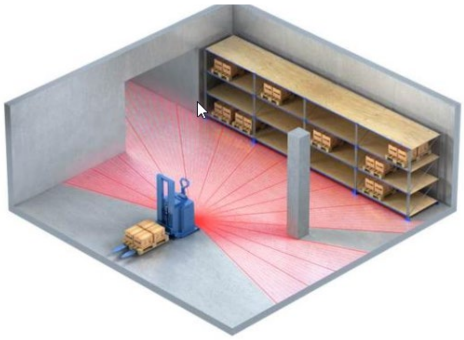

Figure 9: Contour based navigation (Asaprental, 2021)

Multiple different types of navigation can be used to create the perfect navigation system for a company. The manufacturing company can determine the best navigation system through research and stakeholder conversations.

An AGV is a hefty autonomous vehicle capable of severely injuring someone if safety measures are not met. This is why most AGVs have safety stops in place. These safety stops can be found on the machine and close to the machine. AGVs also use the sensors mentioned above to avoid unsafe situations. Lastly, safety bumpers and scanners are in place to monitor driving directions.

Floor control management system

The third component an AGV needs is a floor control management system. This system ensures that delivery tasks are allocated and that (un)loading times are minimized. The system also calculates how the AGV should drive to minimize waiting times at (un)loading stations. (Un)loading stations are locations within a factory or warehouse where the AGV picks up or drops off products. The system utilizes a non-traditional optimizing algorithm (Kumar, 2016). For efficient control of the AGV, two different control systems are used.

Stationary control system

The stationary control system is located in the plant where the vehicle operates. The stationary control system is a central computer unit that manages all software-related actions. Its role is to maintain the administration of the transportation order, communicate with other control systems, and provide graphical visualization to the user.

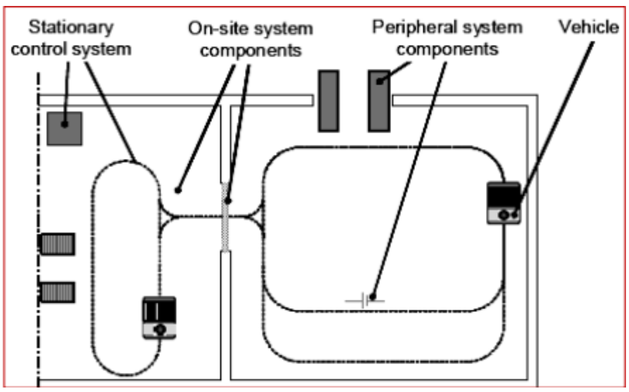

Figure 10: AGV control system (Kumar, 2016)

Peripheral control system.

Peripheral control systems manage the onboard equipment of the vehicle. These are, for example, the battery charging dock or the load transfer mechanism. The peripheral control systems can be located anywhere in the plant where the vehicle operates.

An AGV has a typical delivery cycle. This consists of first loading the product at the loading station. The loading station is a location where the AGV can pick up products. The next step is travelling to the drop-off station. The final step is unloading at the drop-off station.

The time it takes an AGV to complete a delivery cycle is calculated in the following way (Kumar, 2016):

$$T_e = T_l + \frac{L_d}{v} + T_u + \frac{L_e}{v}$$

T_e = delivery cycle time (min/delivery)
T_l = time to load (min)
L_d = distance travel load to unload station
v = carrier velocity
T_u = time to the unloading station
L_e = distance the vehicle travel until the start of the following delivery station

An AGV is a significant expense for most companies. Prices can range from 14,000 up to 300,000 euros. These high prices mean that companies must research whether an AGV is viable. An AGV can be a viable solution if the company requires a flexible, precise, and automated way of transporting material. By estimating how much an AGV saves annually and comparing this to the cost of acquiring one, an estimation can be made whether or not an AGV is a good investment.

2.5 Conclusion

This chapter answered the question *What literature aids with analyzing and improving the current situation?* Through the study of Lean methodology, we have discovered methods for identifying bottlenecks and mapping production processes. These include using spaghetti diagrams, time value maps, and value stream maps to map the current situation at Eternit. Additionally, we employ the Theory of Constraints to pinpoint and resolve bottlenecks, ensuring that the most significant issues are addressed, and solutions are thoroughly evaluated. We found that brainstorming is the most effective method to generate and evaluate ideas. We can establish conditions and criteria that potential solutions must adhere to by generating many ideas. Lastly, we found literature on Automated Guided Vehicles (AGVs) helpful in potentially acquiring an AGV for Eternit.

3 Current situation

This chapter answers the second knowledge question: *'What is the current situation within the factory?'*. The chapter has the following structure:

Section 3.1 Provides a general overview of the factory and its layout. It contains a detailed ground plan provided by the company and a simplified ground plan to map all the forklift movement easier.

Section 3.2 Contains the spaghetti diagrams. There are three spaghetti diagrams depicting the situation on three different days. There is also a diagram depicting all the different paths driven within Eternit.

Section 3.3 Shows the creation of the time value maps and the data needed to create them. This section also provides which sheets and fittings are analyzed. The time value maps are analyzed to find where the most value is wasted within the production process.

Section 3.4 Contains the value stream maps for the top-selling sheet and fitting. The value stream maps are analyzed to determine whether the production process is effective.

Section 3.5 Gives a conclusion and answers the second knowledge question.

3.1 Current situation: General overview

This section contains an overview of the company's layout in full detail. Figure 13 depicts the layout of the company’s premises. The ground plan shows the arrangement of all the properties' facilities, including the factory, unused land, and warehouses. The ground plan represents everything located on the company's property. The red box shows the part where the research is conducted, which is the inside of the factory.

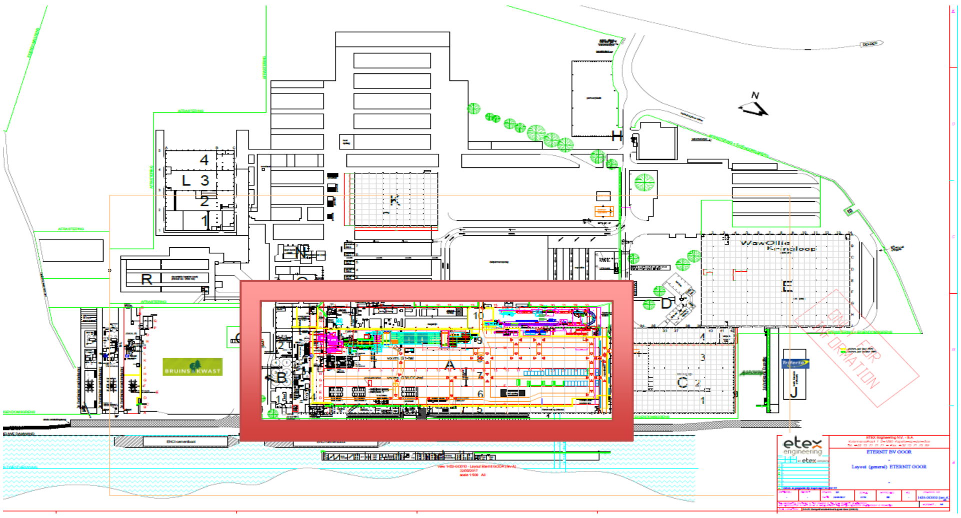

Figure 11: a complete overview of the company's grounds (Eternit B.V.)

Figure 14 contains the simplified ground plan. It has been narrowed down to just the basics and is not scaled. The reason for this is that it is not necessary for the research. Figure 14 shows everything needed to show forklift paths.

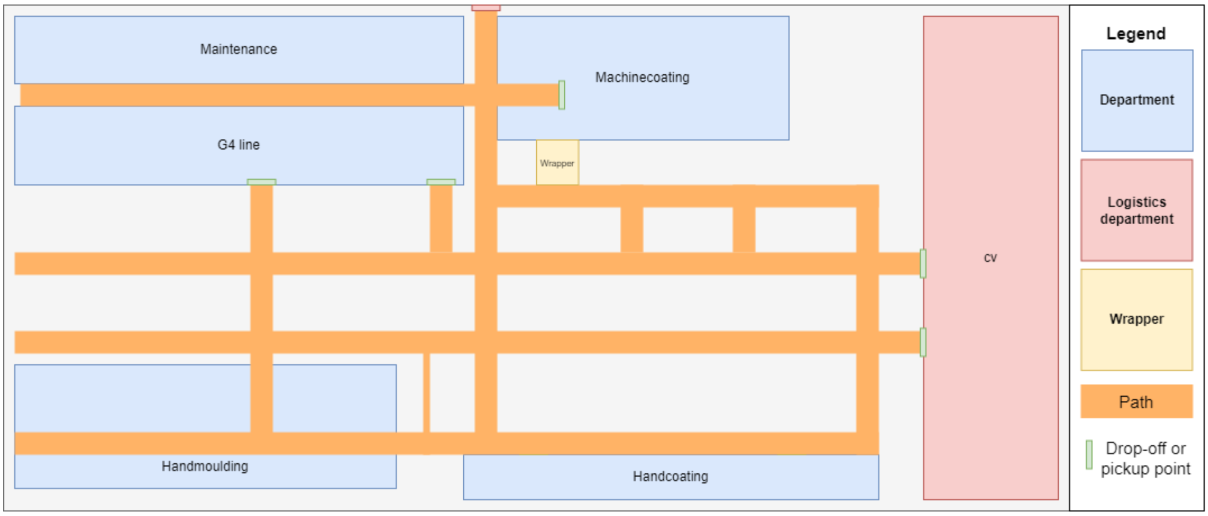

Figure 12: Simplified overview of the factory

As can be seen in the legend, the blue sections in the diagram depict four of the five main departments described in Section 1.1. The red box shows the fifth department, namely the 'logistics department.' The logistics department has a unique role. When the logistics department takes over, the pallet is taken from the factory into one of the warehouses. Since the warehouses lie beyond the scope of this research, the logistics department is the end of our analyses. The orange lines show the possible paths that the forklifts can take. In between these paths are storage areas filled with mostly semi-finished products. The paths are shown since the forklifts cannot drive through or underneath the semi-finished products. The green rectangles show where products are handed from one department to the forklifts and taken to another or storage department. These rectangles are indicated since the products cannot be picked up from any arbitrary point. They have specific pickup points (the end of the assembly line, for example). The yellow box indicates the location of the wrapper. The wrapper is not one of the five main departments, but it is a machine used very often, so many products pass through that point.

3.2 Current situation: Spaghetti-diagram

Using a spaghetti diagram, we can quickly and clearly show all the transportation done within the factory. Currently, 15 forklifts are in operation at the factory from Monday to Friday, with the hours of operation being 6:00-14:00 and 7:30-16:00. The spaghetti diagrams show the areas with the most traffic, helping to identify potential bottlenecks before conducting a value stream analysis.

The upcoming sections go in-depth into these potential bottlenecks. The observations to create various spaghetti diagrams are done over three days and combined. The observations are all done for 1 hour. This ensures that all paths are shown and nothing is left out.

Figure 15 shows the paths examined during the first day of observations. On the day prior to this day, the G4 line was broken. This meant that the factory could not operate at its total capacity, and there was less traffic within the factory. This could be seen because most forklifts were outside the factory. The forklifts that were driving only moved a small number of products. Most transport was done between machine coating and the wrapper and from there to one of the storage locations. On this day, no potential bottlenecks are found. The reason for this was the low amount of traffic. There are more days when factory traffic is lower. Therefore, it could be helpful to observe whether or not potential bottlenecks are also noticeable. This is why we chose to include this day in the research.

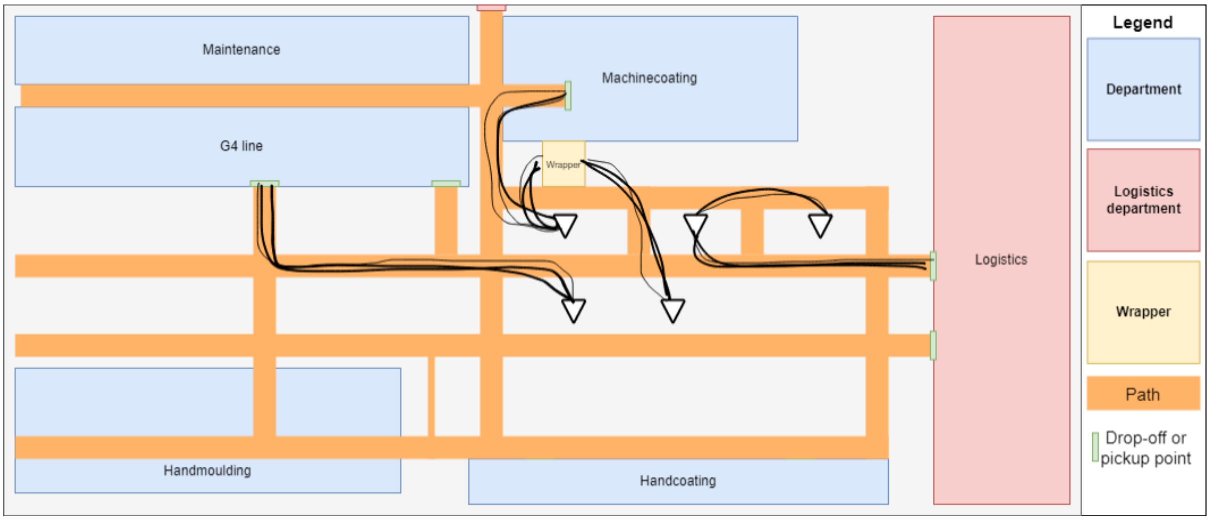

Figure 13: Spaghetti diagram day 1

On the second day, we made observations at two different times. The first observations began at 10:00 in the morning. The preparations are made for the machine to operate at total capacity in the afternoon. The G4 line had just started producing, and the machine coating department was also preparing to start operations. While this is happening, many products are placed in front of the machine coating department to get coated. Next, many finished products are moved from the factory to the outside warehouses. This meant that many movements were from outside the factory to inside the factory or the other way around.

On the second day, we conducted afternoon observations at 13:00 when the factory was running at total capacity. This allowed for the observation of more forklifts and their paths. As shown in Figure 16, there was a significant increase in traffic during the afternoon. Most of the transportation took place in the upper half of the factory, where the G4 and machine coating are located. As a result, the transportation in this area was repetitive. There were also small amounts of traffic within the hand coating and hand moulding departments. However, these were not recorded as they occurred infrequently and did not create any bottlenecks.

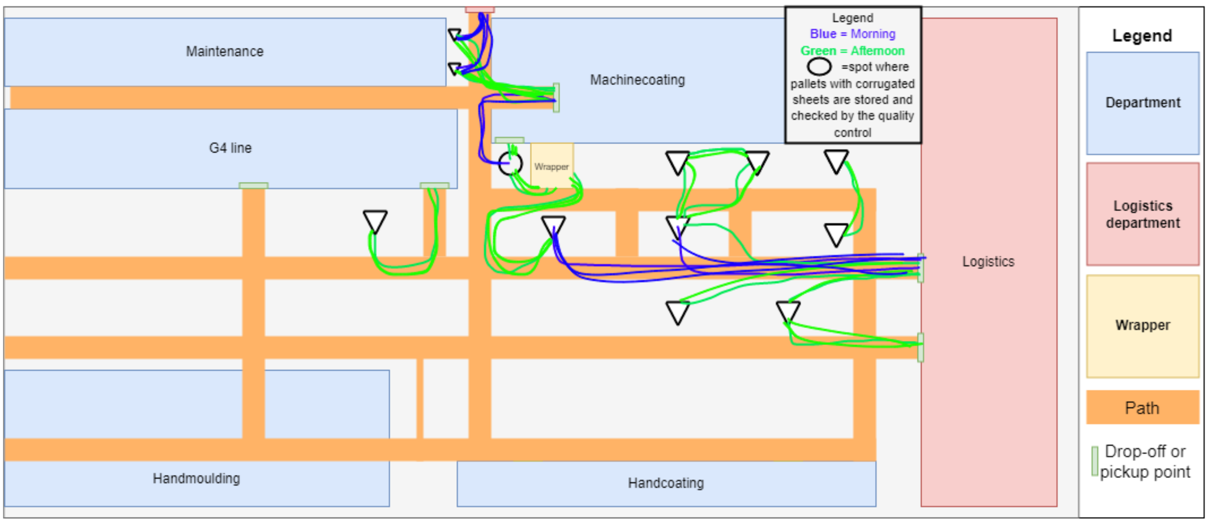

Figure 14: Spaghetti diagram day 2

On the third day, we conducted observations twice; once from 10:30 to 11:30, and the observations are presented in Figure 17. Unlike the previous day, the factory did not have start-up time. It was already running at full capacity when the observations began. There was a significant overlap in movement patterns between days 1, 2, and 3. However, on this day, there was a notable increase in traffic around the hand coating and hand moulding departments, and to a lesser extent, around the G4. Several potential bottlenecks were identified during the observations, which will be discussed later in this section. The afternoon observations were done from 13:30 to 14:30, and not much new movement was observed. The bottlenecks identified during the earlier observations were also present during this time.

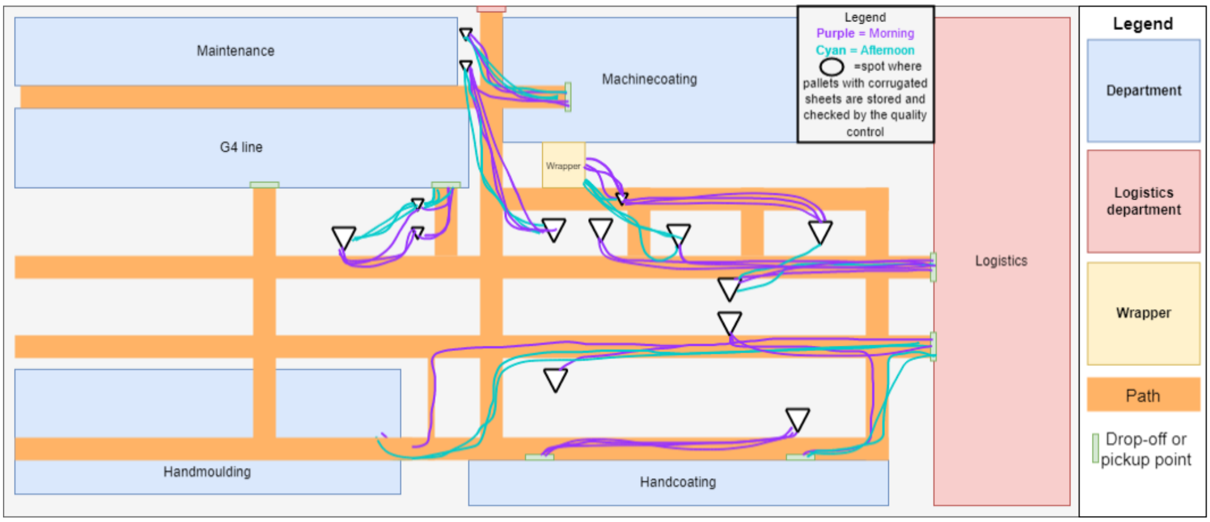

Figure 15: Spaghetti diagram day 3

Figure 18 shows all the forklift movements within the factory without any overlap. The overlap is removed so that all the different paths are shown clearly. The remainder of the paths not shown in Figures 15 until 17 are gathered from interviews with forklift operators and logistical managers. All the various flows are indicated with unique colours, which are explained here:

Black Transport of semi-finished products from the end of the G4 line to interim storage.

Blue Transportation of semi-finished products from interim storage to warehouse by the logistics department.

Red Transportation from the G4 interim storage to the saw machine and then to the saw storage(the red triangle).

Purple supply of semi-finished products from the warehouses outside the factory or the internal storage to the coating line.

Green The flow from coated product to the wrapper, from wrapper to interim storage, where it has to dry for 24 hours before being taken by logistics to the warehouse.

Cyan Supply of moulding plates from the G4 line to the hand moulding department. This happens with a trailer and not with a forklift. From the hand moulding department, the product is stored in interim storage. From there, it goes to the ready-for-hand coating storage.

Pink Transportation to and from the hand coating department. The products transported to the hand coating department are transported from the logistics department. The reason for this is that there is some temporary storage placed there.

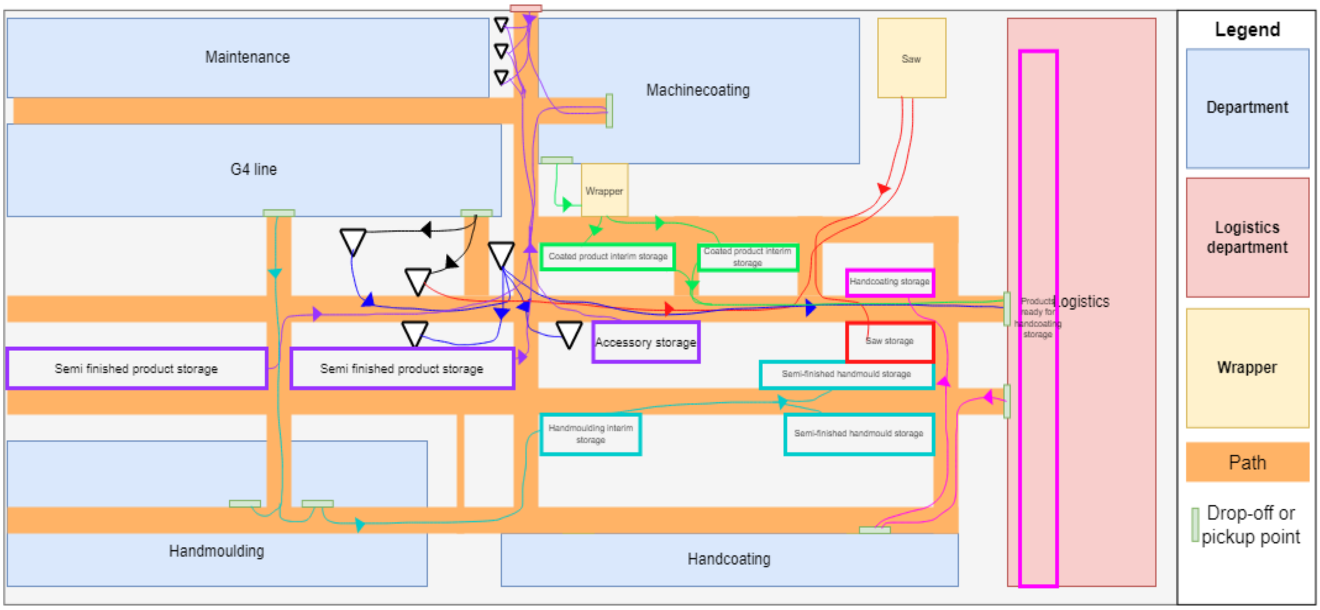

Figure 16: Final spaghetti diagram including all flows and storage spaces

During the three days of observation, information about forklift movements within the factory was gathered. This information will be utilized to perform a value stream analysis in the upcoming sections. Additionally, the spaghetti diagrams and observations revealed some potential bottlenecks. These include:

Unnecessary movements: During the research, it became apparent that some pallets are moved from one spot to another, just to be moved back later. These movements seemed redundant and unnecessary. When removing these extra steps, the handling times should be reduced. In addition, these extra steps could form a potential bottleneck.

Traffic jams: One crossroad within the factory gets busy at peak times, causing some forklifts to come to a standstill. This led to crucial time loss and added handling times for the product, creating a potential problem.

One-way doors: There is a door in the factory where products come in from the outside. This door is only meant for one-way traffic, causing forklift drivers to take a longer route when products have to be moved outside, resulting in higher handling times.

3.3 Current situation: Time value mapping

Since Eternit creates many different products, it is impossible to include everything in one time value map. Looking only at the sheets, there are 213 different kinds. According to the plant manager, only the top-selling sheet and the top-selling fitting are considered. These two products go through the steps that almost every other product follows. For this reason, only the 2 top selling products quite well depict the situation for most products. Figure 19 shows the top-selling sheets and their percentage of sales. Figure 20 shows the top-selling fittings.

Product Group:	Article nr:	Description:		Overall Result (pcs):				Percentage t.o.v. omzet:	Opgeteld:
CS	88556	P76 1525 dkg L93NC		287.097				12,7%	12,7%
CS	88557	P76 1525 cut corners dkg L93NC		187.681				8,3%	21,0%
CS	273291	P76 z31.4-168 ES-LD 2500 r.br. L22NC		78.799				6,5%	27,6%
CS	88565	P76 2440 dkg L93NC		69.522				4,9%	32,5%
CS	88560	P76 1830 dkg L93NC		81.317				4,3%	36,8%
CS	115186	P76 1600 dkg L93NC		79.204				3,9%	40,7%

Figure 17: Top-selling sheets

Product Group:	Article nr:	Description:		Overall Result (pcs):				Percentage t.o.v. omzet:	Opgeteld:
Fitting	6861	P76 K-ridge upper WL310mm dkg L93NC		71891				18,0%	18,0%
Fitting	6860	P76 K-ridge under WL310mm dkg L93NC		74192				17,5%	35,5%
Fitting	6876	P76 M-bargeboard 2200 dkg L93NC		22142				11,8%	47,3%
Fitting	7417	M-bargeboard natural		5501				2,0%	49,3%
Fitting	7003	P76 M-bargeboard 2200 blck L91NC		4009				2,2%	51,4%
Fitting	7389	P76 K-ridge upper WL310mm natural		9580				1,7%	53,1%

Figure 18: Top-selling fitting

Section 2.1.2.3 explains the concept of time value maps. Two time value maps are created for the aforementioned corrugated sheet and fitting. Before creating these maps, research is conducted on the data regarding the actions required to produce the sheet or fitting. This research is conducted by observing the production processes and interviewing relevant stakeholders. Figure 21 and Figure 22 depict the actions that the corrugated sheet and the fitting undergo and identify the type of value each action adds. For further clarity on these values, refer to Section 2.1.2.2. When an action is Non-Value Adding (NVA), the desired time should be 0 seconds.

The times and desired times of all actions are presented. The desired times are the times that occur when no waste is present within the process. Therefore, all desired transportation times are set to 0 as transportation is considered a waste. Additionally, the total time and the total time 2 are presented. The total time 2 excludes the hardening and the drying actions. These times are also fixed and cannot be influenced. With the drying and hardening times included, the difference between the total and total 2 for the sheets is only 1.9%. However, the difference is 68.5% without these times, which is a significant gap. The difference is calculated as follows:

$$\frac{|actual\ time - desired\ time|}{desired\ time}.$$

Step	Action	Value	Actual time(s)	Desired time(s)
1	Taking product from the G4	NNVA	15	15
2	Transporting product to first interim storage	NVA	35	0
3	Transporting product to second interim storage	NVA	60	0
4	Hardening	VA	28800	28800
5	Transporting product from outside to machinecoating	NVA	160	0
6	Transporting product to machine coating line	NVA	25	0
7	Placing product into machine coating line	NVA	10	0
8	Coating product	VA	400	400
9	Taking product from the coating line	NNVA	15	15
10	Transporting product to quality control	NVA	60	0
11	Quality control	VA	150	150
12	Transporting product to wrapper	NVA	15	0
13	Placing product into the wrapper	NNVA	15	15
14	Wrapping	VA	210	210
15	Taking product from the wrapper	NNVA	10	10
16	Stacking product	NNVA	25	25
17	Transport to third interim storage	NVA	60	0
18	Transporting product to warehouse	NVA	150	0
Total			30215	29640
Total 2			1415	840

Figure 19: Datasheets

Step	Action	Value addir	Actual time(s)	Desired time(s)
1	Taking product from the G4	NNVA	30	30
2	Placing product onto cart	NNVA	90	90
3	Transporting product to handmoulding	NVA	240	**0**
4	Placing product into punching machine	NNVA	120	120
5	Punching	VA	1000	1000
6	Transport to moulding location	NVA	240	**0**
7	Product placed in mould	NNVA	6000	6000
8	Hardening	VA	28800	28800
9	Taking product from mould	NNVA	20	20
10	Transporting product to interim storage	NVA	300	**0**
11	Hardening??		3 weeks	3 weeks
12	Transporting product to handcoating	NVA	35	**0**
13	Placing product at handcoating	NNVA	25	25
14	Handcoating	VA	2000	2000
15	Drying	VA	57600	57600
16	Transporting product to warehouse	NVA	240	**0**
Total			96740	95685
Total 2			10340	9285

Figure 20: Data fitting

Figure 23 and Figure 24 show the time value maps. The actions within the maps are the same as those in Figure 21 and Figure 22. The actions are colour-coded according to their added value. Green is value adding, yellow is necessary non-value adding, and red is non-value adding. Within the time value maps, hardening, drying, and coating processes are not included for the sheets. Hardening, drying, coating, and placing a product in a mould are not included for the fittings. These times cannot be changed and make the time value maps unclear because of their duration.

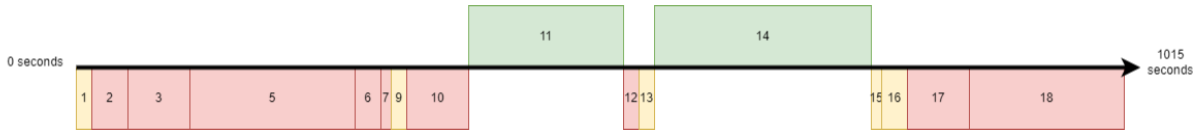

Figure 21: time value map sheets

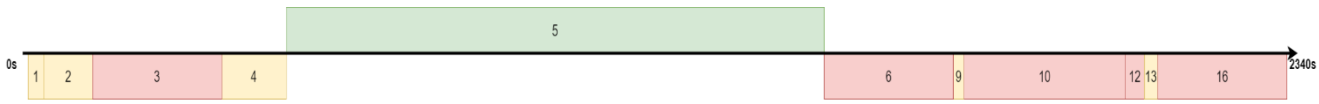

Figure 22: Time value map fitting

The time value maps show that much time in the process is non-value adding. In reality, the percentage of non-value-adding time is smaller than the time value maps might suggest since drying, hardening, and coating are omitted. In reality, about 1.9% of the time is non-value adding, with the hardening times included for the sheets. Without the hardening times, this percentage goes up to 68.5%. For the fittings, these percentages are 1.1% and 11.3 %, respectively. Almost all of this time is wasted on transportation. According to Lean, transportation is a waste that should be eliminated whenever possible. In total, 575 seconds are wasted on transportation for each pallet with corrugated sheets and 1055 seconds for each pallet with fittings. This can be reduced by researching possibilities to remove some transport or shorten transportation times. Chapter 4 describes the solutions to this research.

3.4 Current situation: Value stream mapping

Section 3.3 shows where the most time in the process is wasted. Value stream maps can are created with the data collected to create the time value maps. Value stream maps can show where waste occurs within a business process and where lead times are the highest.

Figure 25 illustrates the complete production process to create one pallet with corrugated sheets. A pallet contains 50 corrugated sheets when examining the top-selling product. The process comprises of 11 different actions. Most of the actions that the products undergo occur while they are stacked on a pallet. The value stream map indicates that for all pallets with sheets that are created, 0.13hr of waiting time occurs. With a production time of 8.8 hours, the process is 98.5% effective. An effectiveness of 98.5% is very high, indicating that lead times are minimal. However, lead times cannot be eliminated as they happen when the sheets must be coated and when the pallets are stacked. Therefore, improving manufacturing a pallet with corrugated sheets cannot be achieved by changing the manufacturing processes.

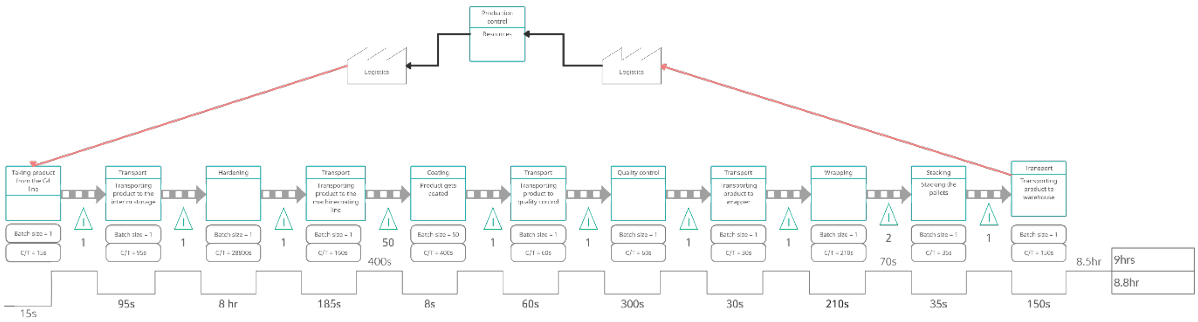

Figure 23:Value stream map sheets

Figure 26 shows the complete production process to create one pallet with fittings. A pallet contains 100 fittings when looking at the top-selling fitting. The process consists of 16 different actions. Action 11, the second hardening action, is not included. The reason for this is that it takes three weeks. This makes both the value stream map and the percentage of effectiveness inaccurate. It is also a process that cannot be influenced or changed, so leaving it out does not change the research outcome. As with the sheets, the processes are mostly done when the fittings are stacked onto a pallet. This is the case for every step except punching, mould placement, and handcoating. The value stream map shows that for all pallets with fittings created, 2.5 hours of waiting time occurs. The total production time of 26.9 hours means the process is 90.7% effective. An effectiveness of 90.7% is very high. This means that the lead times are meagre. When creating a pallet of fittings, the lead times occur when the fittings have to be moulded or coated. Changing these processes is very difficult and falls outside the scope of this research.

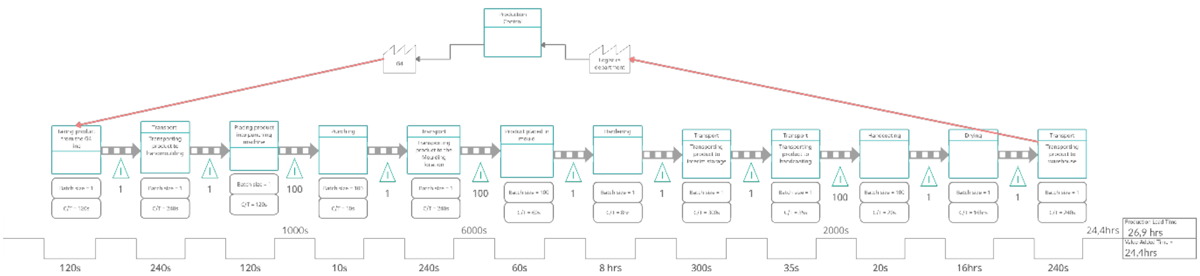

Figure 24: Value stream map fitting

A4 contains enlarged versions of Figure 25 and Figure 26 for better visibility.

3.5 Conclusion

This chapter has answered the following knowledge question *What is the current situation within the factory?* The spaghetti diagrams show where the most traffic is located within the factory. This is around the G4 and machine coating areas. The spaghetti diagrams have also shown where potential bottlenecks can cause handling times to be higher than expected.

The time value maps have shown which actions are considered waste and which are not. The time value maps also showed the duration of all actions a fitting or sheet undergoes. With this, it can be seen which actions should be reduced or eliminated to eliminate waste and decrease handling times.

The value stream maps have shown the complete business process to create a finalized pallet with sheets or fittings. The value stream maps show where the most lead times occur and visualize the business processes in an organized manner. Next to this, it can be seen that the business processes' effectiveness is very high, meaning there is not much waiting time in the process.

Most waste is caused by transportation. Other wastes, such as waiting times, cannot be reduced in this business process. Chapter 4 describes the ways and methods used to reduce transportation and decrease handling times based on the findings in this chapter.

4 Possible solutions

This chapter presents solutions for Eternit to reduce its handling times based on interviews and research. The chapter is structured as follows:

Section 4.1 Describes the conditions that Eternit stakeholders set to ensure that proposed solutions are viable and fit within the business.

Section 4.2 Describes the ideal situation for Eternit.

Section 4.3 Describes the solutions in more detail. It goes over the AGV solution, changing the one-way doors solution, and changing the warehouse layout solution.

Section 4.4 Compares the solutions to the conditions from Section 4.1.

Section 4.5 Concludes the chapter and answers knowledge questions 3 and 4.

4.1 Conditions

To find the best solution for a research problem, we need to set up certain conditions that the solution must meet. These conditions may include costs, safety, and other important factors. It is crucial to involve stakeholders from Eternit and Etex in the process to guarantee a comprehensive list of conditions.

We held a brainstorming session to gather input from important stakeholders. The plant manager from Eternit and the supply chain manager from Etex participated. They both have a lot of knowledge and power to influence the research and the problem we are trying to solve. The researcher was also present at the session to help guide the discussion and keep it organized. During the session, the stakeholders brainstormed individually for 10 minutes before discussing and refining their ideas to create a final list of conditions. After the brainstorming session, the list of conditions was agreed upon by all stakeholders. Setting clear and well-defined conditions for a solution is essential to ensure it is effective and meets the needs of everyone involved.

1. The working area cannot become less safe after implementing one or multiple solutions. *Etex's safety standards are very high, so they want to keep the high safety standards after implementing a solution.*
2. The current building cannot be changed or enlarged. *This is a condition since changing or enlarging the building is costly.*
3. No digging in the ground inside the factory. *Eternit has thick concrete floors that are hard to penetrate with a drill or other machinery. Underneath the floor are pipelines that can cause significant damage to the property if damaged.*
4. The payback time of a solution can be three years at maximum. *If the payback time is longer than three years, Etex does not see it as viable.*
5. The business process has to become more effective or cost less after implementing solutions.
6. The G4- and machinecoating lines can not be moved. *The G4- and machinecoating lines are huge and heavy machines. Moving them would be too costly and time-consuming.*
7. The solution must work with the current pallets, machines, and systems that Eternit currently uses. *The proposed solution has to fit within Eternits current way of working*
8. The solution has to be easy to use and possibly program. *Since Eternit has a large variety of workers with different levels of education, a solution has to be easy to use and program.*

9. The law cannot be broken at any point within Eternit.

4.2 Ideal situation

This section describes what the ideal situation would be for Eternit. This ideal situation is decided following the wishes and needs of the most influential stakeholders. Interviews and observations of current operations are conducted to create the ideal situation. In the ideal situation, the least amount of transport occurs within the factory. Only necessary transportation occurs with as little wasted time as possible. This can be achieved by perfecting routes and warehouse layouts, among other things. Transportation has to use as little manpower as possible, and no waiting times should occur. All transportation is done according to the most logical way of working possible. Transportation that can be removed is removed. If there is transport that can be improved by automation or another solution, it should be improved. Not all transportation can be automated since automation costs much money. Other solutions or automation to improve transport must comply with the conditions mentioned in Section 4.1. The solutions mentioned in this chapter will try to bring the actual situation as close to the ideal situation as possible.

4.3 Solutions

In this section, we present several solutions for Eternit to optimize its production logistics, focusing on reducing handling times. As previously discussed in Chapter 3, transportation is a significant contributor to waste at Eternit, and addressing this issue is a key objective of this research. The solutions presented here are based on a literature review and interviews with relevant stakeholders. These solutions can be combined to form a comprehensive plan. Chapter 5 explains this plan. The proposed solutions are as follows.

4.3.1 AGV

In Section 2.4, information about AGVs is searched and explained. This section uses that information to create a detailed plan for Eternit to consider acquiring an AGV. The subjects explained in this section regard costs, safety, and how much an AGV will improve the current situation and decrease handling times at Eternit. Chapter 5 explains the implementation plan.

Location

Before looking at the type of AGV that can be used, the location has to be determined. There are 2 locations within the factory where an AGV can be used. Other transport within the factory cannot be automated since it is impossible to implement an AGV there. The reason for this is that the space is too small. Using an AGV at these two locations leads to one or more forklifts being purposeless. This will improve the current situation by automating transportation and cost less money in the long term. This is because an AGV is a one-time investment in replacing forklift drivers that cost money each year. If the AGV is acquired, it is profitable within three years since, otherwise, it does not meet Etex's criterion. The first location is between the G4 line and the handmoulding department. This AGV will move sheets from the G4 to the handmoulding department and residual waste from the handmoulding department to the waste location. The second location is between the handcoating department and the warehouses. Inside the factory is a long path from the G4 to the outside warehouses. Transportation there currently costs much time. An AGV could do this transportation at night so that during the day, everything is ready to be coated. This could decrease the transportation times during the day a lot. Transportation during the day causes forklifts to wait for each other, increasing the handling times. Transportation during the night does not decrease handling times. However, it improves the production process during the day, when the factory operates and more traffic is present.

Limitations

A few limitations were discussed during an interview with the sales engineer at WEWO techmotion. WEWO techmotion is a company specializing in creating and delivering AGVs to companies in the technology sector. This discussion led to a few limitations that Eternit has when buying an AGV. The first issue is that the pallets are very heavy, which can cause a problem for the AGV. An AGV has a predefined maximum load. Most AGVs have a maximum load of around 1500kg. The pallets at Eternit can reach a weight of 2500kg. In consultation with WEWO, it is concluded that it is possible to carry such high weights. However, it means that the AGV becomes very costly. The second issue is that Eternit does not possess a warehouse management system. The lack of a warehouse management system limits the usability of an AGV to simple tasks. This means that the AGV has to come with a local warehouse management system to know where to pick up and drop off pallets. The warehouse management system is another factor that adds to the costs of acquiring an AGV. Because of the previously mentioned limitations, the costs of an AGV could become very high. The high costs could mean that the payback time becomes longer than three years, leading to an AGV not being a viable solution.

Safety

Safety is a crucial thing for Etex. It tries to maintain the highest safety standards possible to keep the workplace as safe as possible for all employees. Since an AGV is an autonomous vehicle that can be very heavy, it can be dangerous if safety measures are not met. During the interview with WEWO, some safety measurements were mentioned that the AGV uses. The first thing is sensors. Every AGV comes with sensors that constantly measure its surroundings. Suppose it senses that a pedestrian or other vehicle is close by. In that case, it slows until the pedestrian or vehicle has passed. There is also a sensor that measures in very close proximity to the AGV. If that sensor senses something is very close, the AGV makes an emergency stop. Secondly, every AGV has a mounted blue light. This blue light shows where the AGV is headed for other people to see. This blue light ensures that nobody is confused about which direction the AGV is headed. Thirdly, there are barriers around the perimeter that ensure no one gets stuck between the AGV and a structure or wall. These barriers are located close to these structures, so the AGV never drives too close to them. Lastly, manual safety stops around the workplace can be used as a last resort if all other safety measures fail and an unsafe situation occurs. When someone presses this safety stop, the AGV immediately stops moving. These safety measures should ensure that an AGV can operate safely between pedestrians.

Costs

AGVs can be a costly expense for most companies. Depending on the type of AGV, prices can vary from 14,000 to 300,000 euros. An estimate of the payback time for an AGV is calculated through a cost-benefit analysis. It should be noted that this estimate may vary based on factors such as the type of AGV selected, labour costs, and installation expenses. The costs are estimated based on interviews with AGV manufacturing companies and research. The savings are from data provided by Eternit.

Costs:

AGV unit cost: estimated at 140,000 euros

Personnel costs for AGV operation and maintenance: estimated at 20,000 euros

Training costs for AGV operation and maintenance: estimated at 10,000 euros

Total costs: 170,000 euros

Savings:
Reduced labour costs: estimated at 55,000 euros per year for one full-time employee
Reduced costs for forklifts/electric carts: estimated at 10,000 euros per year
Total savings: 65,000 euros per year
Payback time: 2.6 years (calculated as 170,000 / 65,000)

This cost-benefit analysis shows that the acquisition of an AGV for Eternit would have a payback time of 2.6 years, making it a financially viable investment in the long term.

Changing the one-way doors after 17:00
Within the factory, a door only allows for one-way traffic. This door is located next to the machinecoating line. The door was designed to allow regular traffic; however, due to safety concerns, it was changed to one-way traffic. This rule caused the transportation time to increase significantly since the forklift drivers have to take a way longer route to reach the warehouse. In a conversation with various forklift drivers, it became clear that after 17:00, this one-way traffic rule was unnecessary. After 17:00, the factory's traffic is so low that safety measures can be adhered to even when the door allows for regular traffic. Reverting the door to regular traffic after 17:00 reduces transportation time by 100 seconds per pallet and can be implemented without any changes or investments to the factory.

In order to fully implement this solution and ensure the safety of all employees, certain safety measures must be put into place. These measures will not only ensure that the rules of the one-way door system are followed but will also keep the level of safety as close to that of using a one-way door as possible.

One potential measure that can be implemented is placing a digital sign above the door. This sign would indicate whether the door can be used as a one-way or regular door. This measure would decrease the chances of the door being used regularly before 17:00, ensuring that the one-way door system is followed correctly.

Another potentially more expensive measure is installing a sensor at the door. This sensor could detect from which side the forklifts are arriving at the door. Once the sensor detects that a forklift is approaching from the inside, the door can be programmed to only open after 17:00. This measure would eliminate the risk of forklift drivers using the door as a regular door before 17:00, ensuring the proper usage of the one-way door system.

A final measure that can be implemented, although it may be met with controversy, is the installation of cameras that a foreman or someone with a managing function can monitor. This measure would allow for the monitoring of employees and ensure that the one-way door system is followed. However, it should be noted that Eternit does not monitor their employees with cameras, so not all employees may like this measure.

4.3.2 Changing the warehouse layout

Eternit creates many different products, which results in a significant amount of storage space being used in their factories. Even though this research does not consider the warehouses located outside the scope of the study, the factory storage is still too large and complex to be analyzed within the scope of this research. Currently, Eternit stores its corrugated sheets in various locations within the factory according to the production schedule. This leads to an inefficient layout that changes frequently, resulting in increased handling times and decreased product flow.

One solution to improve the flow and decrease handling times is through warehouse slotting. This involves organizing products based on their sales volume or ABC classification. The ABC classification is a method of categorizing products based on their sales volume or movement, where "A" items are the most popular or fast-moving, "B" items are less popular or slow-moving, and "C" items are the least popular or non-moving. By organizing products based on this classification, Eternit can create fast-pick areas for frequently ordered products, which can reduce transportation times and improve product flow.

Another solution is to place products that sell the most closer to the G4 line or the exit to the warehouses. This way, the forklift drivers have to cover less distance each time they move a pallet with these products. However, there are some limitations to these solutions. First is the space. Eternit has limited space within its factory which is not enough to store all its products. When the layout is not optimal, and forklift drivers have to drive to the outside warehouses more often than needed, this increases the handling times. The second limitation is consistent with the limited space: pallets can only be stacked four high. This is because when five or more pallets are stacked atop each other, the bottom pallet gets crushed because of the high weight. The last limitation is that Eternit works with a first-in-first-out methodology. Because of this methodology, the warehouses have to be designed so that the oldest product can always be taken out of storage even if new products have been placed around it. Despite these limitations, changing the warehouse layout can be a cost-effective solution with high ROI. It is worth considering for Eternit to improve its warehouse operations.

4.4 Comparing solutions

4.4.1 Conditions

In this section, the solutions presented in the previous section are evaluated against the conditions outlined in Section 4.1 to determine their viability. It is important to note that all conditions must be met for a solution to be considered viable and compared with other viable solutions. Figure 27 displays the three solutions at the top and the conditions on the left. The corresponding cell will be marked green if a solution meets a given condition. The cell will be marked red if a solution does not meet a condition. If a condition is not met but is deemed acceptable by stakeholders, the cell will be marked yellow. This allows for a straightforward visual representation of which solutions meet the necessary conditions and can be considered viable options.

	AGV	Changing one way doors	Changing warehouse layout
Safety can not be reduced			
Current building can not be changed			
No digging inside the factory			
Payback time 3 years maximum			
Business process has to become more effective or cheaper			
G4- and machinecoating lines can not be moved			
Solutions has to work with current pallets			
Easy to use and program			
Law can not be broken			

Figure 25: Solutions and conditions

The AGV solution meets all nine conditions because it improves the flow and decreases handling times while adhering to Eternit's high safety standards. It can be implemented without changing or enlarging the current building and does not require digging in the ground inside the factory. It has a payback time of less than three years, making it a cost-effective solution. It also works with the current pallets, machines, and systems Eternit currently uses, and it can take into account the outside warehouses and the pedestrians in the actual implementation. The AGV solution is designed to be user-friendly, and it can be programmed to fit the specific needs of Eternit's operations, and it complies with all relevant laws and regulations.

Changing the one-way door after 17:00 meets all nine conditions and is a simple and inexpensive solution that improves the flow and decreases handling times. It can be implemented without changing or enlarging the current building and does not require digging in the ground inside the factory. It has a short payback time and works within Eternit's current way of working. The solution can be easily implemented and does not require special programming or technical knowledge. It also complies with all relevant laws and regulations. However, it should be noted that it may have a small impact on safety. However, it has been deemed a viable solution by the EHS manager at Eternit as long as a safety analysis is performed and safety measures are implemented.

Changing the factory layout meets all nine conditions as it reorganizes the warehouse layout to optimize the flow of products, reducing handling times and costs and allowing for more efficient use of space. This solution can be implemented without the need to change the physical structure of the building or dig into the floor. It also considers the limitations of pallet stacking and complies with all relevant laws and regulations. This solution can also be customized to suit Eternit's specific needs and can be easily integrated with current systems.

4.4.2 Comparison

This section compares the proposed solutions by evaluating them based on several criteria, each rated on a scale of 1 to 5. A rating of 1 means the solution does not fulfil the criteria, while a rating of 5 means it is an ideal fit. For instance, a solution that scores a 5 for the criterion 'safety' is considered very safe. During an interview with the plant manager from Etex, a list of criteria and the weights for each criterion were discussed. The criteria are the following:

- Costs (weight: 0.2)
- Safety (weight: 0.2)
- Future vision (weight: 0.1) *how futureproof is a solution? Does it fit well within Eternits plans for the future?*
- Ease of use (weight: 0.15) *how easily can employees use the solution?*
- Ease of implementation (weight: 0.1) *how easily can the solution be implemented?*
- Durability (weight: 0.1) *is the solution usable in the long term?*
- Decrease of handling times(0.15) *How much does the solution decrease the handling times?*

Table 2 shows how each solution scores on the criteria using weighted scores. The criteria were weighted based on their importance for Eternit, as discussed during an interview with the plant manager. As per the weights, costs and safety are the most important criteria when evaluating a solution, with a weight of 0.2 each. The rest of the criteria have been assigned weights based on relative importance. The table shows that all solutions have almost the same total score. Out of a total possible score of 5, the solutions score an average of 3.8. This means that all solutions are usable for Eternit and will improve the current situation. Chapter 5 explains what solutions are best to use in which scenarios and how to implement these solutions.

Solution → Criterion ↓	**AGV**	**Changing the one-way doors**	**Changing the warehouse layout**
Costs	0,4	1	0,8

Safety	1	0.8	1
Future vision	0.5	0.3	0.2
Ease of use	0.6	0.75	0.6
Ease of implementation	0.4	0.5	0.3
Durability	0.5	0.4	0.4
Decrease in handling times	0.3	0.3	0.45
Total	3.7/ 5	4.05/5	3.75/5

Table 2: Solution Comparison

- The AGV solution scored 1 on safety, the highest among the three solutions. This is because AGVs are automated and can be programmed to follow set safety protocols and procedures, reducing the potential for human error. Changing the one-way doors is another safe solution. However, it relies on the employees following protocol, increasing the risk of human error. Changing the layout of the warehouse does not change safety after being implemented, so it is a safe solution.
- Changing the one-way doors solution has a score of 1 on costs, which is the highest. This is because changing the one-way doors is cheap, requiring minimal investment and time. Changing the layout of the warehouse can also be done cheaply, but it is more expensive than changing the one-way doors, and it costs a lot more time and manpower. The AGV is the most expensive solution since it is a significant investment, with prices going up to 300,000 euros.
- Changing the warehouse layout solution has a score of 0.2 on future vision, which is the lowest among the three solutions. This is because changing the warehouse layout may not be as sustainable and long-term oriented as the other two solutions since it is possible it has to be done multiple times when the market shifts.
- The AGV solution has a score of 0.3 on the decrease in handling times, which is the lowest among the three solutions. This could be because AGVs may not decrease the handling times by a lot. However, automation improves the flow and the AGV can drive during times that no one is present at the factory. Changing the warehouse layout has the highest probability of decreasing the handling times the most, so it has the highest score. Changing the one-way doors decreases the transport time per pallet by 100 seconds.
- Changing the one-way doors solution has a score of 0.75 on ease of use, which is the highest among the three solutions. This is because changing the one-way doors is relatively straightforward and does not require extensive training or changes in employees' workflows. The AGV and changing the warehouse layout solutions both score a 0.6, this is because it takes some getting used to when implementing these solutions.
- Changing the warehouse layout solution has a score of 0.3 on ease of implementation, which is the lowest among the three solutions. This is because changing the warehouse layout requires significant planning and coordination, making the implementation process more complex and time-consuming. Implementing an AGV is relatively simple for Eternit since most of it is done by the manufacturing company. Changing the one-way doors has the most straightforward implementation since it only requires creating some rules and installing safety measures.
- The AGV solution has the highest durability, this is because the AGV is made of durable materials that are designed to withstand long-term use. The other two solutions score lower since, when the factory has to be changed, it is possible that the layout of the warehouse or the location of the doors has to be changed, making them less durable.

4.5 Conclusion

This chapter has answered two knowledge questions. The first is *"How can the handling times be decreased?"*.

According to our research, three solutions lead to a decrease in handling times. The first and most important one is the acquisition of an AGV. This AGV could automate a few transportation routes. Automating transportation routes means that Eternit could get rid of one or two FTEs. This will both be cost and time effective. Another conclusion is changing the one-way doors after 17:00. This decreases transportation time per pallet by 100 seconds. The last solution is changing the layout of the warehouse(s). Changing the layout of the warehouses decreases transportation times and improves flow.

The second knowledge question addressed in this chapter is "What is the best solution?". After consulting with key stakeholders, it is determined that all proposed solutions would improve the current situation. However, it is also concluded that the AGV solution has the highest priority. Changing the one-way doors was also considered a viable solution. However, it is acknowledged that could potentially decrease safety by a small margin. As a result, it would need to be discussed with stakeholders from Etex before proceeding.

Additionally, changing the layout of the warehouses was also seen as a viable solution. It will be kept under consideration for further research within Eternit. Chapter 5 presents an implementation plan for Eternit to maximize efficiency.

5 Implementation

This chapter answers the following knowledge question *'how to implement the solution.'* This chapter describes how Eternit should approach the implementation, who should do what tasks, when specific tasks should be done, and the best sequence to implement these solutions. Chapter 5 has the following structure:

Section 5.1 describes the order in which Eternit should implement the solutions.

Section 5.2 describes the approach Eternit should take when implementing solutions.

5.1 Order of implementation

We recommend that Eternit prioritize implementing the most important solution, the AGV system, first. This solution is the most time-consuming and expensive. However, it is essential to address the current issues in the factory. However, this implementation can be carried out concurrently with the other solutions as an external company will primarily handle it. After the AGV system, we suggest implementing less costly and easier solutions such as changing the one-way doors after 17:00, which is a simple and inexpensive solution and changing the layout of the factory warehouse, which may take longer but is still relatively affordable. By implementing multiple solutions simultaneously, Eternit can save time and quickly address the current issues within the factory.

5.2 Approach

To successfully improve the current situation and decrease the handling times, Eternit has to perform various steps. Since the three solutions are independent of each other, it is not required to implement one solution before another. We will describe what steps Eternit has to take per solution to ensure it is possible to implement it.

Acquiring and installing an AGV inside the factory is the most crucial step in this implementation plan. To reach this stage, budgeting, a safety analysis, and an analysis of the factory must be conducted. Once these steps are completed and no issues are identified, Eternit can acquire an AGV.

Budgeting
Eternit is part of the Etex group, which means that Eternit cannot make significant investments without permission. This means that the Etex group must decide whether an AGV is a worthy investment for Eternit. To gain approval from the Etex group, the AGV needs to have a maximum payback time of three years. To calculate the 3-year payback time, create a budget estimate by contacting three suppliers, obtaining quotations, comparing them, and selecting the best one. Then, discuss the cost viability of the AGV with the Etex group. If approved, Eternit can proceed with acquiring the AGV.
Safety
As mentioned previously, Eternit and the Etex group highly value safety. Since an AGV is an autonomous vehicle that drives in-between pedestrians and forklifts, it has to be very safe. To make sure that an AGV is safe enough to be implemented, a safety analysis has to be performed. This analysis can be done by either the EHS manager at Eternit or someone from the AGV manufacturing company. Etex, Eternit, and the AGV manufacturing company have to discuss this safety analysis.
Factory analysis
To install an AGV, the factory has to be analyzed. Since an AGV can be large, there must be enough space to function correctly. Eternit does not have a fixed product location or warehouse management

system. This can lead to very limited usability of an AGV. Eternit and the AGV manufacturing company must thoroughly analyze the factory to determine the necessary changes to the factory layout to optimize the AGV system's performance.

To change the one-way door, a safety analysis has to be performed. This has to be done by the EHS manager at Eternit. This safety analysis has to contain data that shows how much the safety decreases by using the door regularly after 17:00. The safety analysis should also contain which safety measures have to be put in place to maintain Eternit’s high safety standards.

When changing the layout of the warehouse, a factory analysis must be conducted. This analysis can assist in not only this solution's implementation but also the implementation of the AGV solution. An individual from either Eternit or the AGV manufacturing company can conduct the factory analysis. The analysis must comprise of the current location of all products, storage areas, forklift routes, and fixed objects such as the G4 line. Once this information is gathered, Eternit can analyze the optimal placement of products to minimize handling times. The factory analysis should include both the factory warehouse and external warehouses for optimal results.

6 Conclusion, recommendations, and discussion

This chapter is the concluding chapter of this report. This chapter contains the conclusion, the discussion, and the recommendations for Eternit. It consists of the following sections.

Section 6.1 Provides a conclusion to all knowledge questions based on the research. This section gives a summarized overview of the findings.

Section 6.2 describes the recommendations given to Eternit.

Section 6.3 discusses the research.

6.1 Conclusions

In the previous chapters, we answered five knowledge questions to find a solution for Eternit to improve the current situation. This section answers each knowledge question. After this, the research question is answered.

What literature aids with analyzing and improving the current situation?

Literature has given much information regarding four different subjects: Lean management, the theory of constraints, idea generation, and AGV literature.

The Lean methodology highlights three main principles and eight types of waste in a production process. According to Lean, there is no final destination for a process, as there is always room for improvement. Lean provides three methods for analyzing and identifying waste in a production process. These methods are relevant to this research. Spaghetti diagrams illustrate the paths and frequency of movement in a process. Time value maps reveal which actions are wasteful and where they occur. Value stream mapping maps out the entire production process and evaluates its efficiency.

The theory of constraints explains how to identify, analyze, and eliminate bottlenecks in a production process using minimal resources through a six-step process.

Idea generation is achieved through brainstorming, a method of generating ideas by gathering a group of respondents with a facilitator. The facilitator poses questions, and the respondents provide as many answers as possible within a specified time frame. After a large number of ideas are generated, it is crucial to select the best ones. This can be done using both the "hits and hot spots" method and an evaluation matrix. The "hits and hot spots" method selects the best options by identifying promising possibilities and organizing them in meaningful ways. An evaluation matrix is a matrix in which ideas are placed on one axis and criteria on another. This process results in a list of valuable ideas.

The automated guided vehicle literature describes what an AGV is. The three main components of an AGV are the vehicle, the guidance path system, and the floor control management system. The vehicle is the central unit of the AGV that moves the products. The guidance path system is the method that the vehicle uses to follow pathways. There are multiple different navigation methods that the AGV can use to follow these pathways. Two examples are laser navigation and landmark-based navigation. The floor control management system is the system that allocates delivery tasks and minimizes (un)loading times). An AGV is a costly expense that can be modified to fit a company's needs.

What is the current situation within the factory?

Chapter 3 analyzes the current situation with a few different methods. The first method is spaghetti diagrams. These spaghetti diagrams show all the paths driven in the factory and the frequency that these paths are driven. The spaghetti diagrams have also shown where the most traffic is located within the factory. This is around the G4 and machine coating area. According to the spaghetti diagrams, three potential bottlenecks are found. The next analyzing method was the time value map. These time value maps were created by timing all actions found within the factory. Timing these actions show the handling times to create a pallet with corrugated sheets or fittings. The time value maps show that much time within the processes is non-value adding. Most of this time is wasted on transportation. The third analyzing method is value stream mapping. Two value stream maps are created to show the complete production processes in a simplified manner. They also include the lead times. The value stream maps conclude that the production processes are very effective and that low amounts of waiting occur. The processes that are not efficient cannot be influenced within the scope of our research.

How can the handling times be decreased?

This chapter presents the solutions proposed to Eternit to reduce handling times and improve its current operations. For a solution to be deemed viable, it must meet specific criteria. The proposed solutions meet these criteria, making them viable options. The solutions aim to bring the current situation close to an ideal scenario. Three solutions have been identified.

The first solution is implementing an Automated Guided Vehicle (AGV) system. The AGV can be installed in two strategic locations, between the G4 and handcoating line and between the handcoating line and the warehouses. These areas currently have long transportation times. An AGV could improve this by operating faster and during off-hours, increasing production efficiency. The AGV system can be made safe by implementing appropriate safety measures. The AGV system has a payback time of 2.6 years, which aligns with Etex's business plan.

The second solution is to alter the use of one-way doors after 17:00. Currently, the doors that connect the factory to the outside of Eternit are only used for one-way traffic for safety reasons. After 17:00, traffic within the factory is significantly reduced. By using the doors for two-way traffic after 17:00, the handling time per pallet can be reduced by 100 seconds. Safety measures must be implemented to ensure the solution is safe, such as using cameras, laser scanners, or signs.

The third solution is to change the layout of the warehouse. The current factory storage layout is not efficient. Products are placed in various locations based on the production schedule for that week. This causes the factory storage layout to change frequently. A fixed layout would improve flow and reduce handling times. High-demand products should be placed closer to the G4 line or exits to achieve this efficiently, reducing the distance forklift drivers need to travel. However, there are limitations such as space constraints, stacking limits, and Eternit's first-in-first-out methodology. A complete analysis is not possible within the scope of this research. However, recommendations regarding this solution are still proposed to Eternit.

What is the best solution?

All three solutions proposed to Eternit are compared using criteria relevant to the stakeholders. The solutions all score above 3.6/5, which means they improve the current situation at Eternit when implemented correctly. According to the most relevant stakeholders, the AGV solution has the highest priority. The stakeholders believe this solution is the most beneficial in terms of efficiency and how futureproof it is. Table 2 also shows that the AGV solution scores the highest in all the criteria. The other solutions are also considered viable. However, they do not require such significant investments or change the current situation as much as an AGV would.

How to implement the solution?

The recommendation is for Eternit to prioritize implementing an AGV system as the most important solution, as it is the most time-consuming and expensive but crucial to address current issues in the factory. This implementation can be carried out concurrently with other solutions as an external company will primarily handle it. After the AGV system, less costly and easier solutions such as changing the one-way doors after 17:00 and changing the layout of the factory warehouse should be implemented. These solutions may take longer but are still relatively affordable. By implementing multiple solutions simultaneously, Eternit can save time and quickly address current issues within the factory.

To ensure the successful implementation of the solutions, Eternit must take a few steps. For the AGV solution, it is necessary to make a budget estimate and conduct safety and factory analyses. This will help to plan the implementation accordingly. Additionally, to change the layout of the warehouse, Eternit must conduct a factory analysis, and it is recommended to include the outside warehouses in this analysis.

6.2 Future recommendations

Some subjects need further investigation; this section covers general recommendations for further research. These subjects could not be researched within the scope of this research. Eternit can use these recommendations to gain more data into the proposed solutions or show possibilities to even further decrease the handling times when more research is done.

- Researching forklift paths within the outside factories. *Investigating the forklift paths within the external warehouses is essential to improve the current situation by implementing an AGV. This is because neglecting to examine the external warehouses limits the effectiveness of the proposed solution. By analyzing the external warehouses, additional bottlenecks may be identified and addressed, leading to a decrease in handling times.*
- What role do pedestrians play inside the factory? *Since pedestrians do not move a lot within the factory, they are not considered in this research. However, when implementing the AGV solution, pedestrian paths and behaviours must be analyzed to keep safety as high as possible.*
- Possibility to implement an assembly line to move products. *Can an assembly line move pallets or sheets from one location to another? How do the costs weigh up against the advantages of such an assembly line?*
- How will the new forklifts decrease the handling times? *As of now, Eternit is looking to acquire new forklifts. An analysis has to be made on how much these forklifts improve the handling times and whether or not the proposed solutions will still be viable.*
- Assessing the impact of the AGV system on the workforce. *The research suggests that the AGV system can reduce labour costs. However, it is important to evaluate the impact of the system on the workforce. A study on how the AGV system affects employee satisfaction, productivity, and job security can provide important insights for future decisions.*

6.3 Discussion

During this research, we conducted observations and calculations to find the current situation within the factory. We found the current handling times by observing the forklifts twice over three different days, chosen randomly during the same week. We considered that Eternit's production levels vary from week to week, affecting the scheduling and routes of the forklift drivers. This variability may cause slight deviations in handling times. However, it should be noted that the experienced forklift drivers at Eternit aim to complete all actions as efficiently as possible. Additionally, it should be considered that if new forklift drivers were to be hired, it could increase handling times. These deviations do not change the solutions since the solutions are meant to improve the flow by decreasing the handling times or eliminating some actions.

It is worth noting that the scope of this research did not consider analyzing external warehouses, which Eternit frequently utilizes. When implementing and acquiring an AGV, Eternit must take into account the inclusion of these external warehouses as possible pickup and drop-off points. Additionally, a thorough analysis and improvement of the entire warehouse layout were beyond this research's scope and time constraints. However, it was identified as a bottleneck during the analysis of forklift paths. We provided Eternit with general ideas for improvement. However, a complete analysis of the outside warehouses should be conducted when planning to improve the warehouse layout.

Pedestrians were not taken into account during this research, as they are aware of their surroundings, do not move between forklifts and are primarily stationary. However, when implementing the AGV solution, we must consider the safety of pedestrians, as they are considered a vulnerable group. An accident between a pedestrian and an AGV could lead to severe incidents. Therefore, during the actual implementation, we must consider the presence of pedestrians and put safety measures in place.

Reference list

Treffinger, D. J., Isaksen, S. G., & Stead-Dorval, B. K. (2006). Creative Problem Solving: An Introduction (4th ed.). Routledge.

Goldratt, E. M. (1990). What is this Thing Called Theory of Constraints and how Should it be Implemented? North River Press.

Zahrotun, N., & Taufiq, I. (2018). Lean Manufacturing: Waste Reduction Using Value Stream Mapping. E3S Web of Conferences, 73, 07010. https://doi.org/10.1051/e3sconf/20187307010

Derksen, R. M. (2020). Verkeersveiligheid op de productielocatie [Bachelor assignment]. Universiteit Twente.

Pyzdek, T. (2021). The Lean Healthcare Handbook: A Complete Guide to Creating Healthcare Workplaces. Springer Publishing. (pp. 25-41)

Heerkens, H., Van Winden, A., & Van Winden, A. (2021). Solving Managerial Problems Systematically. Taylor & Francis.

Marien, B., & Van Acoleyen, B. (2020). ENGINEERING AUTOMATION Intelligent Logistic Systems & ETEX.

Chinosi, M., & Trombetta, A. (2011). BPMN: An introduction to the standard. Elsevier.

Bicheno, J. R., & Holweg, M. (2016). The Lean Toolbox 5th Edition: A Handbook for Lean Transformation (5th ed.). Picsie Books.

Blijleven, V., Koelemeijer, K., & Jaspers, M. (2016). Identifying and eliminating inefficiencies in information system usage: A Lean perspective. Elsevier.

Theisens, I. H. C. (2018). Lean Six Sigma Black Belt: Mindset, Skill set and Tool set (Climbing the Mountain) (1st ed.). LSSA B.V.

Interfaces, T. (2021). Value Stream Mapping – Visualize the Flow of Goods through a Value Stream. Tulip. Retrieved October 4, 2022, from https://tulip.co/glossary/value-stream-mapping/

Kumar Das, S. (2016). Design and Methodology of Automated Guided Vehicle. Researchgate.

Asaprental. (2021). How does AGV navigation work? ASAP Rental. https://www.asap-rental.com/how-does-agv-navigation-work-asap-rental-china/

Bdaiwi, Y. (2017). Stakeholder Analysis using the Power Interest Grid.

Lean in de Praktijk. (2019). The Lean Six Sigma Company.

Zabala, I. (2022). Project Management Wiki. Retrieved from https://www.projectmanagement.com/contentPages/wiki.cfm?ID=368897

Appendix

A1: Business processes

Within Eternit, a few processes happen (almost) all the time. These processes can be separated into automated processes (G4 and machine coating) and manual processes (hand coating and hand moulding). These processes can best be described using the Business Process Model and Notation model or the BPMN model. A BPMN model builds easy-to-read flowcharts that map business processes and can be shared across organizations and industries.

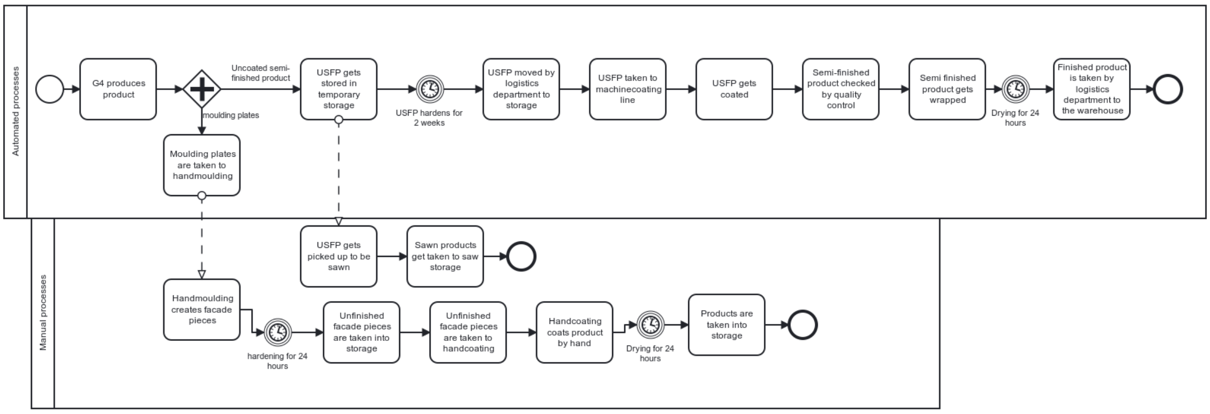

Figure 26: BPMN of business processes

A2: Stakeholder

The best way to start a stakeholder analysis is to put all the stakeholders into a power/interest grid. This grid shows how much power and interest every stakeholder has. Figure 31 shows directly what influence every stakeholder has. Figure 29 is clean, while Figure 30 is with the added stakeholders related to the research project.

In addition to this, the hierarchical structure of the company is shown in Figure 31. This can best be seen in the following cluster. The cluster also shows that most of the stakeholders are related. These relations make it so that almost everyone in the company is involved in the research.

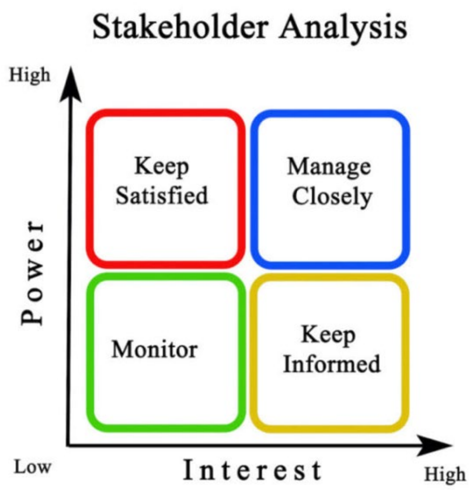

Figure 27: Stakeholder power grid Clean

The diagram shows that the Etex Group has the highest influence because this group decides everything. Eternit BV itself has the second-highest influence. These stakeholders do not have a direct influence on the research, however. This is because it lies beyond the scope of their interest until recommendations have been formulated. During the research, the most important stakeholders are the 'plant manager' and the 'supply chain manager Benelux.' These stakeholders are the ones who created this assignment. Next are all the managers from the different departments within the company. These managers have different interests in the research, so their influence also differs. HR has no direct influence on the research. The health and safety manager has an indirect influence since the research outcome must be safe. The other five managers influence the research since the outcome might affect their departments positively or negatively. Next, we have the forklift drivers; they do not influence the research. Their jobs could, however, be affected since it might lead to a change in the paths they have to drive. It could also lead to a reduction or increase in their workloads. The remainder of the employees (assistants, cleaners) do not influence our research, nor will they experience any effects from it.

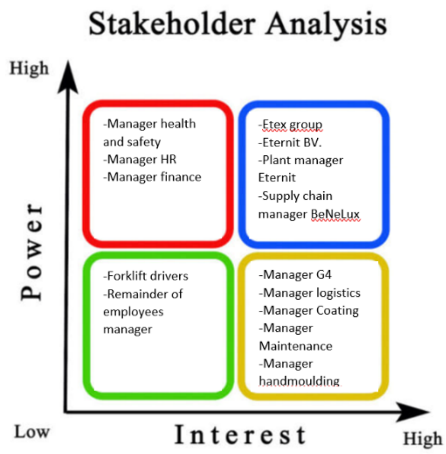

Figure 28: Stakeholder power grid filled out

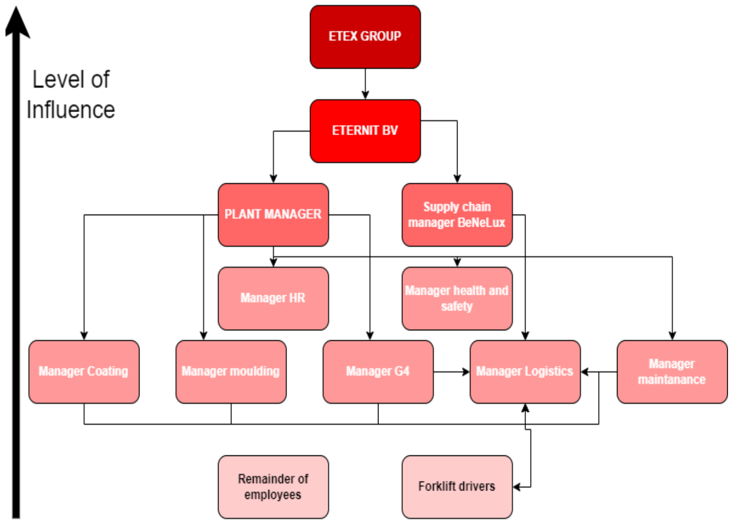

Figure 29: Stakeholder hierarchical structure

A3: Systematic literature review

This part is a continuation of the Section **Error! Reference source not found.**. To understand this part, read Section **Error! Reference source not found.** first.

Inclusion criteria

The key concepts in this knowledge question are stated in the table below. All of the key concepts are also linked to synonyms or alternatives to the concept, creating more freedom in our search terms. These concepts are used as search terms. They are all linked to the knowledge question in some way.

Table 3: Key concepts

Key concepts	Synonym/alternative
Improvement method	Method, improvement

Production processes	Supply chain
Lean	-

Databases

The key concepts and their alternatives mentioned in Table 3 forms the search terms to find the correct literature. The search strategy is using these search terms and combinations of them together with other filters. This should lead to articles and books that fit my search knowledge question. The database used for searching useful literature is going to be Scopus. This database contains a lot of relevant scientific articles and books. Scopus also has an extensive search mechanism that can be effective for finding relevant articles. The search terms and the number of corresponding hits can be found in Table 4.

Table 4: Search terms

Search terms	**Hits**	**Comments**
(Improvement method) AND (Production processes OR Supply chain)	464	A lot of case studies or project-specific results which are not useful for my research.
(Improvement method) AND (Supply chain)	422	Not specific enough, but some relevant literature came up. The next search queries are more specific.
(Improvement method) AND (Supply chain) AND (LEAN)	235	A few interesting articles came up in this search.
(Improvement method) AND (Supply chain) AND (LEAN) LIMITTO: Book, article KEYWORDS: "Lean six sigma", "supply chain management", "improvement"	78	Relevant articles found with this search term that can be used for our research.

In Table 5 there are a few extra criteria mentioned for the literature so that it is viable to use for research. These consist mostly of criteria related to the language or visibility of the article.

Table 5: Exclusion criteria

Criteria	**Reason for exclusion**

The article is not free	If the article is not free to use, it will not be used for research. This is because I do not want to spend a lot of money on articles if there are substitutions available that are free.
The article is in not English or Dutch	If the article is not in English or Dutch, I am not able to read it.
The article is relevant to our research	Some articles do contain all the search terms mentioned above but are not related to my research, hence why they cannot be used.

The full result of the research on Scopus yielded a total of 372 different results. A lot of these results were not useful for my research. The following relevant articles have been found after reading the titles and excluding irrelevant articles. Some articles were also added because of recommendations from my company supervisor.

- Process improvement through Lean-Kaizen using value stream map: a case study in India
- What is this thing called THEORY OF CONSTRAINTS and how should it be implemented?
- Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application
- Lean Manufacturing: Waste Reduction Using Value Stream Mapping

Next, we check if all 4 articles contain the relevant criteria to be used in the research, this is shown in Table 6.

Table 6: Relevant criteria

Article	Improvement method	LEAN	Production process
Kumar & Dhingra & Singh, 2018	X	X	X
Goldratt, 1990	X		X
Gupta & Digalwar & Gupta & Goyal, 2022	X	X	X
Zahrotun & Taufiq, 2018	X	X	X

As can be seen, all 4 articles are relevant to our research. The second article does not contain the "LEAN" criteria, this is because LEAN was invented later than the release of the book. Because of this, it is still included it within the relevant literature.

Table 7 shows what improvement methods the articles suggest and how to use these. This final table is used to formulate a solution to our knowledge question.

Table 7: Article explanation

Article	Improvement method	How does it work?	Usable?
Kumar & Dhingra & Singh, 2018	LEAN-KAIZEN (, or the continuous elimination of waste through small improvements) using a value stream mapping tool.	1)create a value stream map of the current situation 2)identify non-value adding activities 3)create future state VSM	Yes, this is a good way to find non-value adding activities. With this method, it is easy to remove unnecessary steps in the business process.
Goldratt, 1990	Theory of constraints	1) Identify the constraint 2)Exploit the constraint 3)Subordinate everything to the constraint 4)Improve constraint 5)repeat the process	Yes, the Theory of Constraints is a very useful tool for optimizing production processes in our case.
Gupta & Digalwar & Gupta & Goyal, 2022	Theory of constraints & Lean Thinking & Six Sigma	-	No, this article was about how to let LT and TOC work together, not really about how to improve production processes with this technique.
Zahrotun & Taufiq, 2018	Waste Reduction Using Value Stream Mapping	1)Value stream analysis (current state) 2)Waste identification with questionnaires 3)Value stream analysis tools 4)Process activity mapping 5)Fishbone diagram 6)Improvement recommendation 7)Future state mapping	Yes, this method looks like the perfect way to analyze the current situation and find problems and bottlenecks. It is also helpful to create a future state map and fishbone diagrams for the company.

This SLR aimed to identify and evaluate methods for improving production processes. The review identified three relevant articles and three methods for improving production processes. These methods were thoroughly examined and evaluated in consultation with stakeholders to determine their suitability for our research. After careful consideration, it was determined that the theory of constraints is the most effective method for identifying and addressing bottlenecks in a production process. This method is a valuable tool for improving efficiency and effectiveness by prioritizing and addressing constraints in the process. The other two methods, while also useful in certain contexts, were not considered to be as suitable in the context of our research. Therefore, the theory of constraints will be the primary method utilized in our research to identify and address bottlenecks in production processes.

A4: Value stream maps enlarged