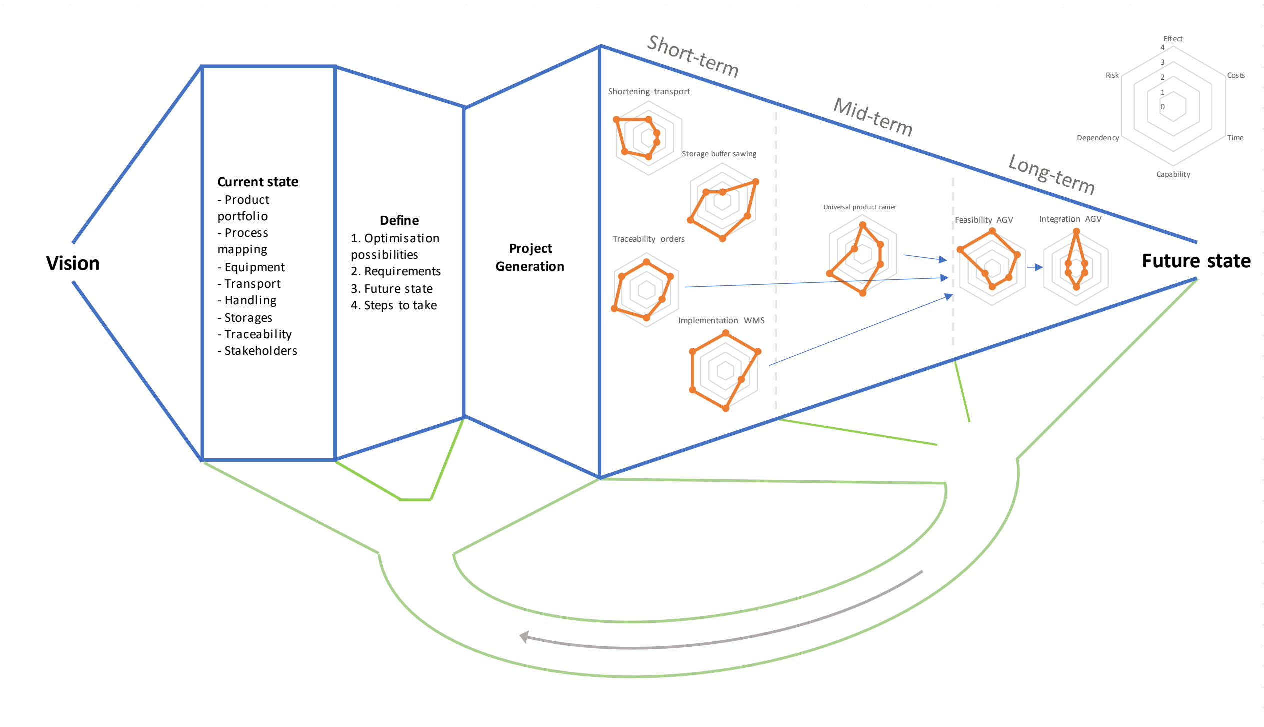
The design of a framework to improve the control, utilisation and flexibility of a metalworking plant by optimising internal logistics



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WILA 90

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Preface

In front of you is the result of the research conducted to complete my masters. This report is about the design of framework that can be used to improve the control, utilisation and flexibility of a metal working plant by optimizing the internal logistics. The metal working plant in this case is WILA B.V. They offered me this assignment on their research and development department for process development. This assignment perfectly suits my interests, since I started my Masters in Industrial Design Engineering three years ago with the intention to develop myself as a process improvement engineer.

This study comes now to an end with the completion of this thesis. This last part was a though journey but I succeeded which makes me proud and grateful. I had not expected that I would still learn so much with the execution of a thesis project. Especially, by going back to the root of the company before starting an optimization to make sure that it is well funded. That is one thing that I will take with me for the rest of my career. Furthermore, I developed myself on a personal level as well which I will also take with me. Although, it was sometimes hard, I still enjoyed the assignment and I am looking forward to continue on this topic at WILA as a Process Engineer.

All this was not possible without the help and empathy of so much people around me. Some of them I would like to thank in particular. In the first place, Maaike Slot as supervisor from the University of Twente for all the fruitful discussions we had and the words I sometimes needed. In addition, I would like to thank Eric Lutters as chair of my graduation committee and for the help you gave.

From WILA, I would like to thank Frank Rouweler for the useful meetings we had and all the space that I got for this assignment. Who cannot miss is Sander Oude Alink, thanks for our weekly meetings which were not always on the content but no less valuable. All the other colleagues from WILA that supported me I would also like to thank, especially Winand Jansen who offered me this assignment and supervised me in the beginning.

Last but not least, I am very grateful for the unconditional support and love of my fiancé Imke, she was there always for me and she did wat was in her power to help me trough. Also thanks to the rest of my family, friends, housemates and members of the RSK who supported me. This was not possible without all of you!

Above all, I want to thank my Heavenly Father for the support, hope and leading that I experienced during this masters assignment.

I hope you enjoy reading my thesis.

Lieven Jan Westerbeke

Hengelo, 31th August 2023

Abstract

This research focuses on improving the control, utilisation and flexibility of a metalworking plant by optimising internal logistics. The research started with a broad perspective of improving control, utilisation and flexibility, but the focus soon turned to optimising internal logistics.

Therefore, the research investigates what internal logistics is and how it can be optimised by implementing state-of-the-art technologies. However, it is difficult for companies to implement these technologies. For this reason, a framework is being developed using a Research by Design approach to help companies optimise their internal logistics.

This framework consists of five phases: vision, current state, define, project generation and roadmap. In the first phase, a vision should be established as to why a company wants to optimise its internal logistics. Next, a current state analysis is carried out to gain insight into the internal logistics and to explore what can be optimised. How the internal logistics can be optimised is worked out in the define phase, where requirements are defined and a future state is created. The fourth phase is to generate projects based on the previous phases. The last phase starts with the ranking of the projects. This should provide insight for creating the roadmap based on the company's strategy. The dependencies between the projects are important for creating the roadmap. Finally, a feedback loop is added to the framework to allow the roadmap to evolve with changing circumstances.

After the design process, the framework is validated with a case study at WILA. This shows how the framework can be applied and how it is perceived. This will then be evaluated to create an improved final design. This successfully concludes the research. However, further validation and development is needed to make the framework fully operational, which is described in the final chapter.

Table of contents

Abbreviations

AGV – Automated Guided Vehicles

AMR – Automated Mobile Robots

AS – Automated Storage

CPS – Cyber-Physical Systems

ERP – Enterprise Resource Planning System

kg - kilogram

KPI – Key Process Indicators

mm – millimetre

R&D – Research and Development

RMC – Robotic Manufacturing Cell

RFID – Radio-Frequency Identification

RS – Retrieval System

SOTA – State-of-the-art

TMS – Traffic Management System

USA – United States of America

WMS – Warehouse Management System

1. Introduction

This chapter sets the basis for the research. This begins with background information on the offering organisation and the origin of the assignment. Thereafter, the research basis is described, leading to the research questions at the end of this chapter.

1.1. Company background

WILA is the offering organisation for this assignment. WILA is a manufacturer of clamping systems and tooling for press brakes, currently with two production sites in Lochem, the Netherlands, and sales departments in China and the USA. Press brakes are used to bend sheet metal into a desired shape, as shown in Figure 1. The sheet metal is bent by pressing with an upper and a lower tool, both clamped in a clamping system, also known as a tool holder, as shown in Figure 2.

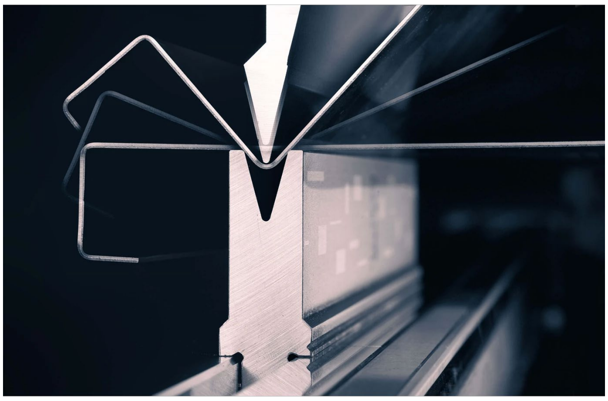

Figure 1 Bending of sheet metal

Since the beginning of 2021, the production of toolholders and tooling has been separated over the two production sites in Lochem. The production of toolholders takes place in the old factory, the Toolholder, at the Goorseweg. The production of the tooling takes place in the Tool, the new factory at the Kwinkweerd. This assignment is carried out at the Tool.

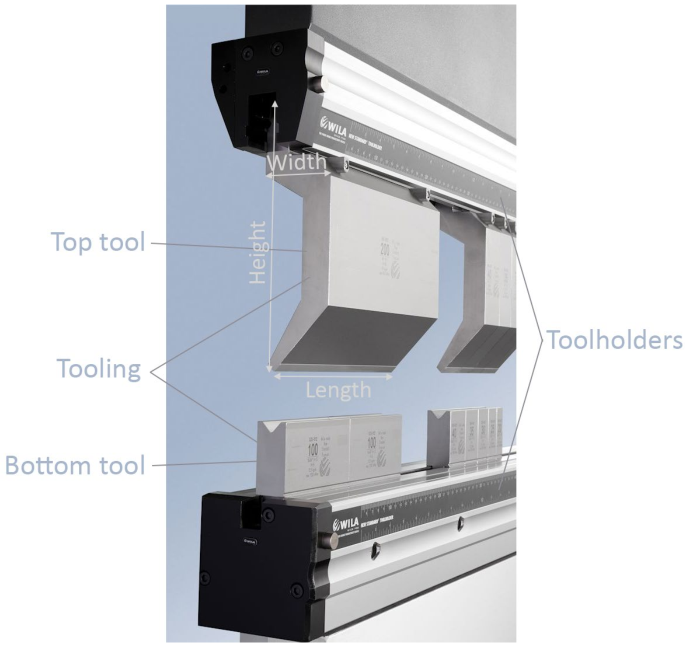

Figure 3 Product overview

As this research focuses on internal logistics, it is good to know what the flow of tooling production looks like, therefore it is shown in Figure 3. This flow can be divided into two sections, from raw material to semi-finished stock and from semi-finished stock to expedition. The different processes are shown in the order of the standard flow, but as can be seen, there is a wide range of routings. This is because this factory not only produces WILA tools, but also white-label products.

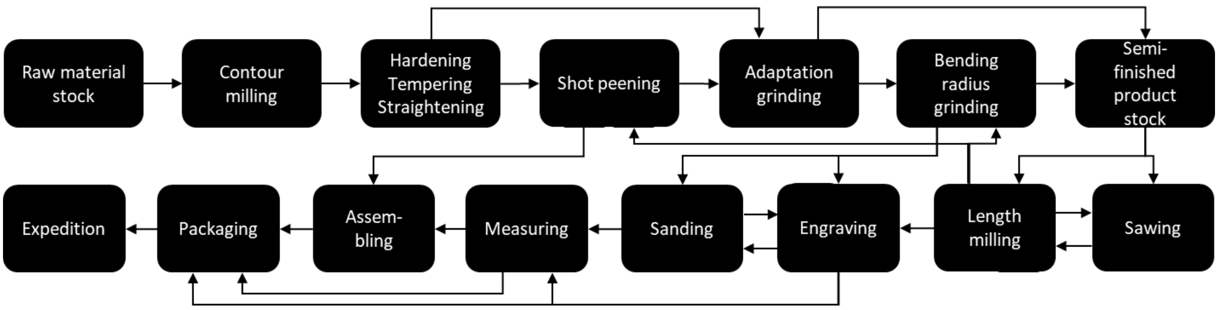

Figure 2 Process overview

The original assignment was to design a universal product carrier that could be used in the second section of the production. The purpose of this product carrier was to standardise the way products were stored and transported, to increase storage density and to prepare for the automation of internal logistics. However, it soon became clear that the added value of the universal product carrier was unclear and that other improvements could have a greater impact on optimising production. It was therefore decided to zoom out completely to find what would the best way to optimise production. This process is described below.

1.2. Research basis

In this subchapter a research opportunity is sought. This search starts by stating the goal of WILA, as this will form the basis of the research. It is the basis because the research must contribute to achieving the goal of WILA. This goal consists of three aspects, which will be explained. Once these have been explained, the next step is to identify opportunities for improvement. After this, a distinction can be made between improvements that are already being implemented and those that can still be carried out. This will lead to an improvement topic that can be used as a research.

1.2.1 Goal of WILA

As a starting point for this research, it is important to know what vision WILA has for the future and what strategy it has to achieve it. The vision and strategy will help determine the direction of the research, so the research will contribute to WILA's goals. Over the next five years, WILA wants to increase its turnover from €50 million to €100 million. To achieve this, WILA plans to increase its production capacity and therefore focuses on improving three aspects: control, utilisation, and flexibility. These three aspects are explained below.

Control

The first aspect is control, which focuses on monitoring and managing the manufacturing processes in the factory. The control of a manufacturing process is often aimed at improving the quality of the process and products, reducing process time, and keeping the production costs low. This can be done in three areas which are process control, inventory control and quality control [17]. The first area is process control, which involves managing and coordinating operations efficiently. Process control also involves monitoring and regulating production equipment and processes.

The second area is quality control. The aim of quality control is to ensure that all products meet the specified quality. To achieve this, materials and products must be checked on arrival, during the process and before distribution. If necessary, the process or product should be adjusted. The adjustment of products and processes costs additional production time. Therefore, having control over the quality of the process can provide a more stable and predictable production process.

The last aspect is inventory control, which can help reduce costs and lead times. Inventory control is about knowing what is in stock and what needs to be in stock to support the flow in the factory. So, the aim is to find a balance for the work in progress between not having too little stock, which would slow down production, but also not having too much stock, which would increase costs [17].

Nowadays, more and more data is available and obtained about the process. This data can be used to provide insights into the production area, but can also be used to better predict and thus gain more grip on the processes [17]. Good control can lead to a better flow through the process and can lead to an increased output of the production processes.

In conclusion, control means that a company gets more insight into its production process. When they know what is going on, it is clearer what can be optimised and where value is added and lost within the production environment. In addition, the predictability of the process increases, which makes it easier to manage the complexity of the many variations.

Utilisation

Utilisation is the extent to which the available resources are used in the best possible way. It includes three types of resources, each with its own form of utilisation. The types are machine utilisation, space utilisation, people utilisation and energy utilisation [18]. The latter will not be included in this research, since it is out of the scope of this research. The first type is machine utilisation, which is the ratio between the time a machine produces products and the total available time of that machine [17], [18]. An optimal utilisation rate is between 80 and 90%. If the utilisation rate is lower, it is likely that the machine is not being operated correctly or that the system has too much capacity, which is a waste of money. On the other hand, the utilisation rate should not be higher than 90%, because then there is no room for maintenance, breakdowns and rush periods without disrupting the flow [17].

The next subject is space utilisation, which can be broken down into two aspects. The first is what percentage of the plant's total area is actually used for production. This cannot be maximised to 100% as there needs to be space for transport, storage and maintenance, but the aim is to use as much space as possible for production [18]. At the same time the factory should not be too full as optimising space utilisation should not negatively affect other aspects such as lead times. The other aspect of space utilisation is storage density. This is the percentage of the total volumetric area of a storage department that is available for the actual storage of products [17].This percentage needs to be maximised because storage space costs money and does not add value, so it needs to be as efficient as possible. However, it is important to keep accessibility in mind [18].

The last subject is people utilisation, the aim is to use operators in the most efficient way. This means reducing work that does not add value and is not supportive, such as unnecessary movement of materials. Another way in which operators are not used efficiently is when they are waiting for work, so this should be avoided [17].

To conclude, the optimization and balance of the utilization of resources, such as machines, space and people, will have effect on the goals of WILA.

Flexibility

The last aspect is flexibility. Flexibility is a broad concept, but in the context of this research flexibility is focused on employability, versatility of capabilities and usability of resources. The aim is to maximise the utilisation of resources by using the same resources to produce a variety of parts and products [17].To this end, a system can be assessed on four points to see how flexible it is. First, whether the processes can produce different types of products. Second, whether the system can respond quickly to changes in the production schedule. Third, whether the system can switch over in case of breakdowns so that production can continue. And fourth, whether new products can be easily added to the product family without causing problems for the system [17].

To achieve this, it is important that planning is flexible, so that it can react to changes in orders. Also, the machines must be flexibly deployable to produce different products. Furthermore, the operators need to be flexibly employable, because when the product mix changes, the workload can also change to other machines, so the employees need to be flexible in their work. Finally, the internal logistics system must be flexible as production depends on it [19].

In conclusion, flexibility depends on control as a lot of insight into the process and control over the process is needed to manage it flexibly. If this is at a good level, it will lead to a more efficient use of operators and therefore a higher utilisation rate.

The aim and vision of WILA is to improve control, utilisation and flexibility in order to improve their processes and production environment and to be able to scale their production facilities in an effective and efficient manner. How this can be achieved is discussed next.

1.2.2 How to improve?

Having stated WILA's goal and discussed the strategy to achieve it, it is time to discuss how things can be improved to achieve the goal according to the strategy. From discussions and analyses at WILA and from literature research, several possibilities for optimising control, utilisation and flexibility have emerged. These possibilities are shown in Figure 4 and are elaborated below. For each component it is described what the improvements are and how they contribute to WILA's strategy.

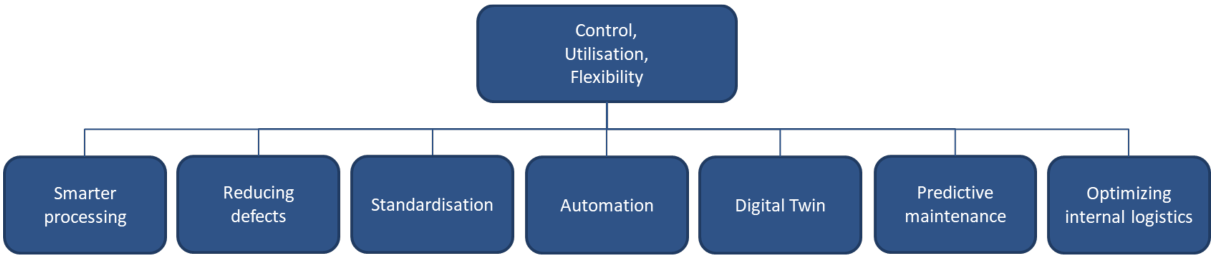

Figure 4 Optimisation possibilities

The first area for improvement is machine utilisation. There are two ways to increase machine utilisation. The first is to have more effective hours per week per machine. This can be done by reducing changeover times or increasing the number of shifts that the machines run [17]. The other way is to produce more products per hour on the machines. This can be done by smarter processing, which means optimising the sequence of operations or combining operations [17]. The other way to produce more products per hour is to reduce defects. When defects are reduced, more good products can be produced per hour [17]. Therefore, good quality control is needed, when this is optimised, the utilisation rate will increase.

The next step in improvement is standardisation, which is useful for all three aspects. Standardisation means that the best way of executing a process is identified and applied in production. This leads to a stable and predictable situation which is the basis for further improvements [20]. In order to apply this in production, the machines must first be standardised to reduce the number of different machines. Once the machines are standardised, the processes can also be standardised, leading to a reduction in the number of different processes. This makes production more manageable and the processes more controllable. Furthermore, when processes are the same, there is more flexibility in production, which leads to better utilisation.

When machines and processes are standardised, it becomes easier to automate these processes because there is less variation [21]. Automation makes it possible to increase the number of production shifts without increasing the number of employees. This is because the work changes from operating the machine to loading and unloading the cell, which is less work [17]. For example, during nights and weekends, automation of processes can allow machines to produce autonomously. Another advantage of automation is that a robot or machine will always perform the same set of actions, allowing for specific instructions on what needs to be done [17]. In addition, more feedback data can be collected, which can lead to better insights and specific adjustments in the process [17]. In summary, automation leads to increased utilisation and controllability. In terms of flexibility, a common argument against automation is that it reduces flexibility, but this depends on the type of automation [22]. If it is guaranteed that all products can be produced in the same way and the machines are the same, then automation can actually lead to increased flexibility by allowing the system to decide autonomously where to produce what [17].

The next option for better control is to create a digital twin of the production process. A digital twin is a digital version of a physical asset. The digital twin uses real-time production data for analysis, simulation and a virtual representation of the production environment. As a result, a digital twin can help provide insight and overview of the production environment. This can be used to control and predict processes [23]

Another system based on data collection is predictive maintenance. Predictive maintenance is a tool that can predict trends, patterns and correlations based on historical data, models and domain knowledge. This can be used to plan maintenance by anticipating failures, but also to prevent over-maintenance. As a result, maintenance costs and downtime will be reduced and productivity and product quality will be improved [24]. Thus, predictive maintenance will improve utilisation, process and quality control.

The final aspect is the optimisation of internal logistics. Internal logistics includes everything related to the movement and storage of materials in a production environment [18]. Internal logistics is not value adding [20], but at the same time internal logistics can cover 20% of total production costs [25]. Despite the fact that internal logistics is not value-adding, it has an important supporting role in manufacturing.

There are two ways to optimise internal logistics. The first is to optimise the manual situation, for example by eliminating unnecessary material handling operations or by applying standardisation. Fewer (different) operations will lead to less work and better overview, which will improve utilisation and control. The other option is to create an intelligent automated internal logistics system. An intelligent automated internal logistics system will be more controllable than a manual system. In addition, it uses real-time data to support production in a flexible and efficient way, which helps to improve machine utilisation. Such a system can also monitor inventory levels, ensuring that management decisions on inventory can be improved, and therefore inventory control can be improved. In conclusion, optimising internal logistics will have a positive impact on control, utilisation and flexibility.

Several options for improving production have been explored. There are many options that contribute to improving control, utilisation and flexibility. Some of these things are already applied at WILA and others are not yet applied. Below is an explanation of what has already been done and what can still be introduced.

1.2.3 What is already done?

In order to research where WILA can optimise, it is first necessary to look at what is already happening at WILA. These aspects can then be excluded from this study. However, these points indicate the ways in which WILA is already optimising and this knowledge can be used. WILA has already taken steps towards standardisation, defects reduction, smarter processing, automation and digital twinning.

In terms of standardisation, WILA now uses the same machines for the same processes. For example, length milling is done with one type of machine, as visible in Figure 5 and this applies to all other processes. In addition, continuous improvements are being made to create uniformity in the way the products are clamped in the machines. At the same time, the products are also standardised to create uniformity in the way they are machined, however, there are still several routings for different products.

Figure 5 Length milling [1]

As mentioned earlier, reducing the number of defects could improve utilisation. WILA is already trying to do this by researching the causes of defects, such as products with too much dimensional variation or products with scratches. This has led to a reduction in the number of rejected products. This means that more good products can be produced per hour, which improves utilisation.

Another option that WILA is already exploring is smarter processing. This means analysing processes to see if improvements can be made to reduce processing time or improve the quality of the product. An example of smarter processing at WILA is the carrier on the sawing machines. In the past, all parts had to be taped to prevent damage, and a semi-finished product had to be clamped twice to saw the segments. In the new situation, as illustrated in Figure 6 the taping is no longer necessary, and the semi-finished products only need to be clamped once. This has improved quality and reduced processing time. Another example of smarter machining is the introduction of a new clamping system on the milling machines. This new fixture allows back deburring, so products only need to be clamped once instead of twice. To conclude, smarter processing might be a good solution for WILA, since it leads to better utilisation caused by the reduction of processing time.

Figure 6 Saw clamping [1]

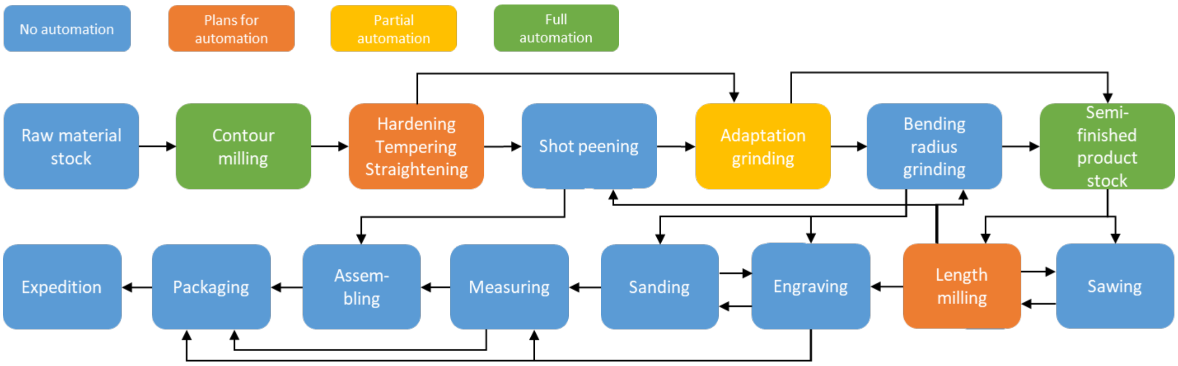

Figure 7 Process automation overview

In the area of automation, several processes are automated or planned to be automated in the tool factory. The degree of automation per process is shown in Figure 7. The first step in the process, the contour milling, is fully automated, as can be seen in Figure 8. The next process, which is hardening, is planned for automation but not yet implemented. Furthermore, there is one automated adaption grinding cell and the next one is under development. Additionally, a project has been launched to develop an automated cell for length milling. Finally, the semi-finished and finished products are stored in automated storage and retrieval systems.

Several projects are being carried out in the field of digital twinning. There is a digital version of the Tool created in Visual Components. In addition, two master's theses are being written for WILA on the subject of digital twinning, with prototypes of a digital test environment and a digital twin in Plant Simulation.

In conclusion, WILA is already taking steps to improve its utilisation, control and flexibility in terms of machine utilisation, standardisation, automation and digital twinning. Therefore, the focus of this research will not be on these points, as this is already known knowledge for WILA.

Figure 8 Contour milling [1]

1.2.4 What can still be done?

To find a research opportunity, there is a search for improvements that WILA may not be familiar with. To find such an improvement, the 'how to improve' section is used to see what is not being done yet. The two remaining topics then are internal logistics and predictive maintenance.

First, the optimisation of internal logistics is investigated. The main aim of internal logistics is to support the production process in such a way that production is not hindered in achieving optimal utilisation. Optimising internal logistics can be done in two ways, which are also related. Firstly, the current situation can be optimised by, for example, reducing the number of material handling operations or reducing the amount of work in progress. Optimising the current situation can lead to an increase in utilisation if operators can work more efficiently and therefore have more time to operate machines. It can also save space by reducing stock. The second optimisation option is to automate internal logistics. Automation can increase utilisation in several ways. For example, machines can take over work from operators, automation cells can be better supplied, and products can be stored more efficiently. In addition, data can be collected to make the system more controllable.

The other new area of improvement is predictive maintenance. Predictive maintenance can predict when maintenance is needed based on live data. For example, if it is known that a tool is nearing the end of its life, it can be replaced before it breaks. Predictive maintenance allows maintenance to be planned so that a machine does not have to wait for maintenance when it is up and running. This results in less downtime. In addition, there will be fewer product defects because products will not be processed with broken tools, as tools will be replaced before they break. In this way, predictive maintenance leads to better control and higher utilisation.

In conclusion, there are two subjects for new improvement at WILA, namely internal logistics and predictive maintenance. One of these will be chosen as the focus of this research, which will be described below.

1.2.5 Research focus

It was necessary to choose a topic to focus on due to the time constraints of a thesis research. For several reasons, it was decided to focus on the optimisation of internal logistics. First of all, the starting point for this assignment at WILA was a request for the design of a universal product carrier. They needed this product carrier to automate their internal logistics, which would be the next step. During the orientation phase at WILA, it became clear that their process was not yet ready for automation. It also turned out that the process could be optimised without automation. In addition, WILA itself focuses mainly on improving the value-adding processes, but not on logistics. This ensures that there is a lot to be gained in terms of internal logistics. At the same time, it is a challenge to implement logistics optimisation because the focus of the process is on the automated production cells. Furthermore, discussions with other companies have shown that other companies are facing the same problems. They are optimising and automating their production processes, but the development of internal logistics is lagging behind, and they do not know where to start optimising their internal logistics. In order to help WILA and other companies to improve their process by optimising internal logistics, this research is being carried out.

1.3. Research questions

Now that the research motive is clear, the next step is to define the research questions for this assignment. These questions should help WILA and other companies to improve the control utilisation and flexibility of their factory. As described above, this research will focus on achieving these goals by optimising internal logistics. This leads to the following research question:

How to improve the control, utilization and flexibility of a metal working plant by optimizing the internal logistics?

1.3.1 Subquestions

In order to answer this research question, several sub-questions have been formulated. These sub-questions will help to answer the main question step by step.

First, it is good to identify what internal logistics is. This is to become familiar with the subject, but also to delineate the area of what is and what is not internal logistics in a production environment. This ensures that not too much is included, but also that things are not forgotten. Hence the question:

1. What is internal logistics?

To ensure that the final solution is relevant to companies and helps them move forward, the right optimisations must be found. The first step is to identify the problems so that it is clear where improvements can be made. The following question explores this:

2. What are the problems of internal logistics for production companies?

Once it is known what can be optimised, it is possible to investigate how it can be optimised. This involves examining what is currently available on the market in terms of technology. Therefore, it is necessary to examine what are the state-of-the-art technologies for internal logistics:

3. What are state-of-the-art technologies for internal logistics?

The next step is to see how these state-of-the-art technologies can be a solution to the problems in question two, resulting in the question:

4. How can state-of-the-art technologies solve problems for internal logistics?

The final step is to align these optimisations with the goals of WILA. Therefore, the question is asked how these technologies contribute to improvements in control, utilisation and flexibility.

5. How can state-of-the-art technologies of internal logistics help to improve the control, utilization and flexibility?

In the following chapter, the above sub-questions have been addressed through research.

2. Internal logistics

This chapter is an elaboration of the sub-questions described above. The answers to the sub-questions will form the basis of the solution. This chapter therefore gathers information that will be needed to answer the main question. The structure of this chapter is therefore based on the order of the sub-questions as they are built on each other. This chapter is not yet a solution, but it is working towards an improvement in control, utilisation and flexibility.

2.1. Description of internal logistics

The first question to be answered is what internal logistics actually is. This will show what is covered by internal logistics and therefore what areas can be improved to achieve better control, utilisation and flexibility in production. Furthermore, describing what internal logistics is also allows for scoping, as it reveals what it does not include.

Since there are a variety of terms and definitions for roughly the same topic, it is good to first establish what terms exist and how they are used in this research. Terms for logistics within production are internal logistics [17], material handling [26], intralogistics [27] and production logistics [28]. Only the term internal logistics has been used in this report to avoid confusion. However, the other terms were used as search terms in this research.

To ensure that everyone has the same understanding of what is covered by internal logistics in this research, a definition was used. To this end, a number of existing definitions were examined. The first definition according to [22, p. 6] is: "All activities and processes connected with managing the flow of materials (and adherent information) within the physical limits of an isolated facility". This definition is partly based on Groover's definition [17, p. 286], which is as follows: "Internal logistics, more popularly known as material handling, involves the movement and storage of materials inside a given facility". The third definition comes from the Material Handling Institute and says: "The movement, protection, storage and control of materials and products throughout the process of manufacture and distribution, consumption and disposal"[29]. This definition is not in line with the other two definitions because distribution, consumption and disposal can take place outside the factory. This also shows that it is good to have a clear definition. As the definition of [22] is clearer than the definition of [17], it was decided to use the definition of [22] for this research.

While this definition is general and therefore abstract, it is good to look at the purpose and function of internal logistics to get more clarity. The purpose of internal logistics is to reduce the costs of production and of internal logistics itself. This is because internal logistics does not add value and should therefore be minimised in terms of costs [18], [30]. There are also sub-goals such as maintaining or improving product quality, promoting productivity and controlling inventory, but these sub-goals also eventually lead to cost reduction. When looking at the objectives of this research, which are control, utilisation and flexibility, they also aim to produce as cheaply as possible. Thus, internal logistics can contribute to this.

The function of internal logistics is to provide the right quantity of the right material, in the right condition, at the right place, in the right position, in the right order, at the right cost, using the right method [19]. To perform this function, equipment is required that can be described using the categories of internal logistics equipment established by [17]. These categories are transport equipment, positioning equipment, unit load formation equipment, storage equipment, and identification and control equipment.

2.1.1 Transport equipment

Transport equipment is needed to move material from one place to another. This can be done in a number of ways, for example the traditional way using industrial trucks (Figure 10) or the modern way using automated guided vehicles (Figure 11) and rail-guided vehicles. In addition, conveyors (Figure 12), hoists and cranes (Figure 14) can be used to move material [17]. The choice of equipment depends on the layout of the factory, the flow of production and the type of products. The right choice of transport equipment can reduce the time and effort required by employees within the factory and so the choice will influence the utilisation of resources within the factory. In addition, the transport equipment will influence the flexibility of the internal logistics and thus the production process. For example, an automatic guided vehicle will be more flexible than a conveyor system [31].

Figure 10 Industrial trucks [11]

Figure 11 Automated guided vehicles [16]

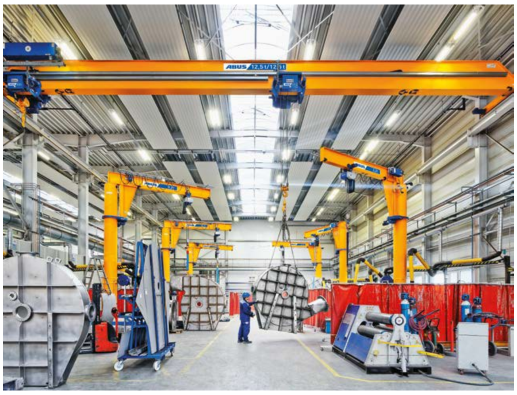

Figure 14 Hoist and cranes [13]

Figure 12 Conveyor [3]

2.1.2 Positioning equipment

Equipment related to transport equipment is positioning equipment. This is used to transfer products over a short distance from unit load formation equipment to the process and back. This can be fixed hoists or cranes, industrial robots (Figure 13) or part feeders (Figure 16)[17]. The choice will depend on the process and the type of product.

Figure 13 Industrial robot [14]

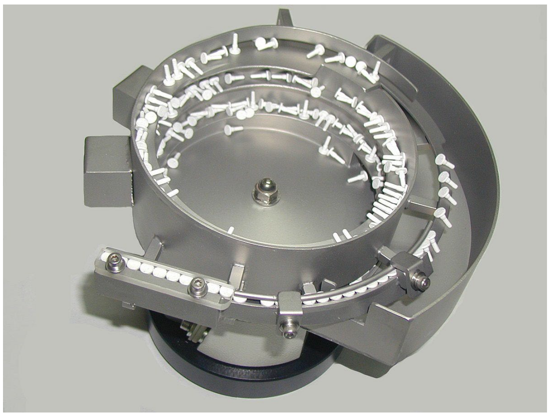

Figure 16 Part feeder [10]

Figure 15 Pallet [4]

2.1.3 Unit load formation equipment

Products are transported in specific batches and therefore unit load formation equipment is required to store the products during transport. Different types are pallets (Figure 15), boxes (Figure 19), tote bins (Figure 18) and specific product carriers (Figure 17) [17]. The size and type of this equipment will depend on the batch size, the product portfolio and the transport, storage and picking equipment. It can also be decided that the transport, storage and pick & place equipment will be based on the unit load formation equipment. Furthermore, the unit load formation will have an influence on the flexibility and utilisation of the factory. A small unit load is better for flexibility, but it also requires more transport and handling, which is detrimental to utilisation. Therefore, an optimum should be found based on the production conditions.

Figure 19 Boxes [5]

Figure 18 Tote pans [15]

Figure 17 Specific product carrier [15]

2.1.4 Storage equipment

This unit load formation equipment is stored in storage equipment, for example as a storage buffer between two processes. This can be done conventionally in racks, shelving, bins and drawer storage or automated in Automated Storage and Retrieval Systems (AS/RS) [17]. The main influences on this choice will be the unit load formation equipment and the size of the storage buffer. The choice of conventional or automated will have an impact on utilisation and control, which will be higher with AS/RS. However, such systems require high investment, so for small storage buffers, conventional systems may be more suitable, or they should be combined into a central automated warehouse.

Figure 21 Racks [6]

Figure 20 AS/RS [9]

2.1.5 Identification and control equipment

The final category is the tracking of products throughout the internal logistics system. This can be done by attaching a label to the individual products or to the unit load. One type of label is a barcode that can be read by a reader, but the proportion of RFID labels is growing. These labels can be read when the label is in close proximity to the reader [26]. By tracking the products, control will increase and so will flexibility, as there will be less strict conditions for storing and transporting products because they are traceable. It also increases efficiency because products are easier to track, so there is no need to search for products and information is easier to provide.

Figure 22 Bar code reader [7]

2.1.6 Conclusion

In summary, internal logistics is the activities and processes involved in managing the flow of materials and associated information to support production. This requires different types of equipment, which can be categorised into transport, positioning, unit load formation, storage and identification and control. The choice of equipment depends on the factory layout, production flow, type of products and batch size. In addition, the choice of equipment in a particular category also depends on the equipment in other categories. Therefore, it is important that internal logistics is not seen as separate parts, but as an integrated system that should be developed together.

2.2. Problems of internal logistics for production companies

As described in the introduction, it is necessary to identify the problems so that they can be solved with the aim of improving utilisation, control and flexibility. To answer the second sub-question, these were identified in several ways. On the one hand through analysis and interviews at WILA and on the other hand based on problems found in the literature. The problems are briefly described here, a more detailed analysis of the problems can be found in the analysis of the current state of the use case in chapter 4.1.1.

2.2.1 Storage buffers

The first problem relates to the storage buffers that are placed between processes. Storage buffers are needed to keep the process flowing. However, these buffers can be too large and then have a negative impact [17], [19]. There are several reasons why storage buffers may be too large. The first is that production is not well controlled. As a result, processes may not be properly balanced or planned. If one process has more capacity than another, there will be shortages or overstocks. Another cause is that logistics and production are not well coordinated. For example, logistics may run on two shifts and production on three. As a result, stock needs to be put on the shelves in the afternoon for the night, so there needs to be enough shelf space for this buffer.

This has two consequences. Firstly, the current storage buffers take up more space than when stocks are lower, so space utilisation is not optimal. Secondly, investments have been made in the material to be processed, but these do not pay off quickly enough when products are in stock rather than being processed, which costs money.

2.2.2 Transport movements

There are transport movements between different processes and warehouses that are necessary to move products. However, there may be unnecessary movements or transport distances that are too long. These redundant transport distances mean that operators spend more time transporting orders than would be necessary in an optimal situation. As a result, they are not working at optimum capacity and there is a risk that the machine will be idle while they are transporting orders, resulting in sub-optimal machine utilisation. The additional transport distances also mean that more forklifts are needed than in an optimal situation.

2.2.3 Handling

Handling is about picking and placing orders and products. These are not value-adding activities and should be kept to a minimum [20]. However, this is not always the case. For example, unnecessary storage buffers or the use of different unit load formation equipment throughout the process can result in more handling than necessary. In addition, manual handling can be ergonomically stressful and repetitive, leading to injuries and operator disengagement. Unnecessary handling and ergonomically stressful tasks can therefore reduce people utilisation and machine utilisation when operators drop out.

2.2.4 Traceability

As described in the previous section, the level of traceability affects control, utilisation and flexibility. Lack of traceability has a negative impact on control since it is not known where products are. Therefore, it is not easy to locate products, resulting in operators losing time while searching which reduces utilisation. A solution is to subject transport and storage to strict rules, but that reduces flexibility. Furthermore, if storage is captured in strict rules, it is not possible to store flexibly, therefore more storage capacity is used than is actually needed. Finally, it is difficult to automate internal logistics if products are poorly traceable.

2.2.5 Conclusion

In conclusion, there are problems with storage buffers, transport movements, handling and traceability. These problems have a negative impact on control, utilisation and flexibility. At the same time, some of these problems are the result of insufficient control of the process. Thus, optimising internal logistics can result in an upward spiral for control. In order to achieve this, it is investigated how this can be done by implementing state-of-the-art technologies, which is described in the following sub-chapters.

2.3. State-of-the-art technologies for internal logistics

This subchapter will answer the third sub-question: "What are the state-of-the-art technologies for internal logistics?" But first, an introduction will be given about why this question is asked. Thereafter will be explained what the state-of-the-art technologies for internal logistics are.

This question should be a step towards solving the problems described above. There are a number of reasons for choosing to explore the state-of-the-art technologies to solve these problems. Firstly, the use of automation in internal logistics has great potential, as handling is time consuming and physically demanding. Through automation, the productivity of internal logistics could be increased [30], [25] and thus the utilisation problems could be solved. Furthermore, [27] and [31] state that the introduction of state-of-the-art technologies will enable more effective control of internal logistics. Finally, the use of these technologies will increase the flexibility of internal logistics [25] [31].

The state-of-the-art technologies of internal logistics are all part of cyber-physical systems (CPS), also known as smart objects or the Internet of Things [27]. Cyber-physical systems are being introduced to improve the flow of information between executive and decision-making technology. The development of these systems is leading to systems with increased computing and communication capabilities. In order to exchange the necessary information, all elements of the system should be able to communicate with each other [25].

The cyber-physical systems could be divided into two parts, namely the digital technologies for decision making and communication and the physical technologies for execution in the factory [31]. The systems are connected by embedded processors, sensors and actuators [27].

Three important digital technologies are Enterprise Resource Planning (ERP), Warehouse Management System (WMS) and Traffic Management System (TMS) [25] [31].

ERP is about managing and planning resources of the supply chain in the factory. When this is integrated with CPS, better forecasting of resources is possible, which improves overall productivity and flexibility [25]. The WMS focuses on warehousing activities, so it processes, among other things, product locations, available storage locations and inventory levels. It can therefore make decisions about the allocation of storage locations and request equipment to move products [25].

TMS focuses on the transport of products, it manages the movement of products. It can make decisions about assigning tasks and finding the most efficient routes. To do this, it needs to know the live location data collected by RFID scanners and sensors, as well as the origin and destination of tasks. The system also takes into account empty vehicle management and deadlock avoidance. The use of real-time data will improve the quality of decision-making and make the system more flexible and efficient [25] [27].

The physical SOTA technologies are described in four categories: transport, pick and place, storage, and identification and control.

For transport, there are three main ways of moving goods by SOTA technologies: automated guided vehicles (AGVs), autonomous mobile robots (AMRs), and conveyor belts.

AGVs are increasingly used for internal logistics [31]. AGVs are independently self-driving vehicles, but require a predefined path to guide them. There are several types of AGVs as shown in Figure 11, which makes it possible to use them for a wide range of products [17].

AMRs are similar to AGVs, but the main difference is that they have the ability to navigate without pre-defined guidance. They are capable of finding routes and avoiding obstacles through the use of sensors. This makes them more flexible than AGVs [32].

Conveyor systems are used to transport large items. These conveyors can be placed on the floor or suspended overhead. However, there should be enough space available that is not needed for other operations. This makes them less flexible than AGVs and AMRs, but they are simpler, more reliable and more efficient for transporting materials frequently [31].

Two SOTA technologies can be used for pick and place: autonomous robots and collaborative robots. Autonomous robots are used to transfer products over a short distance and position them accurately. They can operate independently, but this means that the product characteristics and movements must be programmed. They are therefore less suitable for handling products with different shapes and sizes. For these products, a collaborative robot is more suitable, as it is less predefined. They will work together with humans, but they are not autonomous, but they have more possibilities. However, it is not yet possible for a robot to be as flexible as a human and still be efficient [27].

The SOTA technology for storage systems is the automated storage and retrieval system (AS/RS). An AS/RS can automatically store products in the most appropriate location, resulting in higher storage density. In addition, this system removes the need for operators to store and retrieve, resulting in better people utilisation [17].

The final SOTA technology is identification and control. Radio Frequency Identification (RFID) is the most widely used SOTA technology. RFID transponders are able to continuously collect data from unit load equipment and transport equipment that are equipped with RFID tags. This data is transferred to digital technologies and used for control and decision making [33], [25].

2.3.1 Conclusion

In summary, SOTA technologies are available for all aspects of internal logistics, with the exception of unit load formation equipment. These SOTA technologies work best when they are all connected in a cyber-physical system. For this reason, it is important that internal logistics is developed as a system and not as separate parts, to avoid that it becomes difficult to connect the different parts together. Another reason is that the choices for new technologies will be interdependent. In addition, the choices will depend on the environmental conditions as described in chapter 2.1 and how a company wants to optimise. When SOTA technologies are well integrated into the cyber-physical system, the different technologies will be able to communicate with each other, leading to better decision making. The integration of technologies will help to improve control, utilisation and flexibility and solve the problems described in chapter 2.2. How this can be done is described in the next subchapter.

2.4. Use of state-of-the-art technologies in internal logistics

After exploring the state-of-the-art technologies, it will be investigated how they can be used to improve the control, utilisation and flexibility of production and how they can be a solution to internal logistics problems. This subchapter will answer sub-questions four and five. For each of the above technologies, it will be explained what problems they can solve and how they contribute to improving control, utilisation and flexibility.

ERP can be used to improve the alignment of different processes, resulting in smaller storage buffers. It also provides more control over internal logistics and has a positive impact on utilisation and flexibility, as ERP enables better forecasting of processes.

WMS provides more insight and control, which can be used to improve the management of storage buffers and the allocation of orders. This can have a positive impact on transport distances. In combination with TMS, transport can be further optimised. This leads to better utilisation and more flexibility and control when using real-time data.

Automated transport can take over the transport movements, resulting in better people utilisation. Flexibility varies from system to system, as described in chapter 2.3, but it will increase compared to conventional systems. Furthermore, with automated transport, just-in-time delivery will be possible all the time, which may lead to smaller storage buffers.

Autonomous and collaborative robots are both a solution to the ergonomic stress of operator tasks. They can also continue to perform repetitive tasks without becoming overloaded. So, these robots are good for increasing utilisation, but the flexibility of handling could be decreased by using these robots.

AS/RS will lead to better utilisation of space as the storage density is higher compared to conventional systems. In addition, AS/RS takes over handlings of operators and will therefore lead to better utilisation.

The final technology is RFID, which will solve the problems of traceability and therefore other problems such as flexible storage. RFID is also needed to make the best use of WMS and TMS.

2.4.1 Conclusion

In conclusion, SOTA technologies can solve certain problems, but they are not a solution for everything. Some problems should be optimised by better organisation of the process. In addition, it can be said that the use of SOTA technologies in internal logistics will improve utilisation, control and flexibility. However, there is still a long way to go for companies to move from the current state to an optimally functioning cyber-physical system.

2.5. Conclusion

The conclusion is that there is now a clear picture of what internal logistics involves. It has also become clear what the problems are. In addition, the SOTA technologies have been examined and this has shown that it is important to set up an integrated system. In this system, everything is connected and can communicate with each other for optimal decision making. This can help solve problems and improve control, utilisation and flexibility. However, SOTA technologies are not the answer to everything. Some problems can be solved with simpler solutions than implementing new technologies. This also applies to optimisations that can be achieved in simpler ways. Finding these simple opportunities requires good insight into internal logistics, so insight should be gained first. This insight is also needed to choose the right solutions and technologies for improvement.

So, in theory, it is clear how internal logistics can be optimised to improve control and flexibility. However, for most companies it is not clear how this can be implemented in practice. This requires further research, which is described in the next chapter.

3. Design of solution

This chapter describes the framework which is designed to help companies move from the current state to the future state. This solution was developed following the previous chapter, which described how state-of-the-art technologies could help companies to optimise their internal logistics. However, research and discussions with companies have shown that it is difficult to implement these new technologies in internal logistics because they are far from the current state. Therefore, something had to be designed to help companies move from the current state to the future state.

3.1. Method and scope

The methodology used to design the tool is a common design cycle as shown in Figure 23. This design cycle was carried out using the use case at WILA, but keeping in mind that the solution should also be usable for other companies. Initially, the solution direction was focused on designing a roadmap. This is a logical way to move step by step from a current state to a future state. However, the first step in the design cycle, establishing the problem definition, showed that a roadmap would not be sufficient to help companies. Therefore, a framework was developed to assist in the creation of a roadmap.

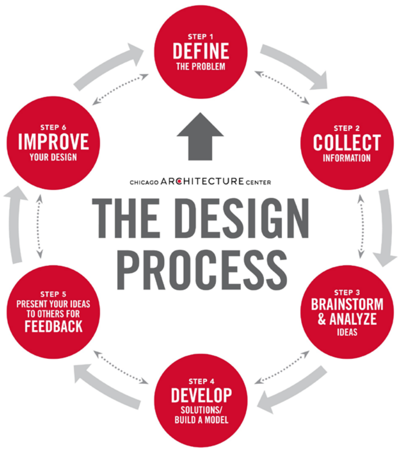

Figure 23 Design cycle [12]

The first step of the design cycle is to identify the problem through a problem analysis, which is described in chapter 3.2. and ends with setting the requirements. For the next three steps the Research by Design approach [34] is used and therefore these steps are intertwined. First the concept development is described in chapter 3.3. and then the concept description in chapter 3.4. At the end of chapter 3 the concept is verified against the requirements. The model is then tested with a use case in chapter 4.1. to obtain feedback from potential users. This feedback is used in the evaluation to find improvements which is described in chapter 4.2.

As mentioned, the scope of the design process is focused on WILA's use case. This means that only the logistical operations related to the products that WILA manufactures are considered. Moving other products, such as tools and chip containers, is therefore not included in the framework design.

3.2. Problem definition

The first step in the design process is to define the problem. It is important to clearly define the problem that has emerged from the preliminary research so that the solution fits well with the companies that want to use it. Therefore, an inventory was made of the reasons why companies find it difficult to optimise and to implement new technologies in their internal logistics system. The reasons that emerged from this inventory are described below.

3.2.1 Too little focus on logistics

The analysis showed that companies are not focusing enough on internal logistics. Companies are more concerned with optimising and automating value-adding processes than with optimising internal logistics. For example, in the use case at WILA, there are 12 people working on improving processes within the factory, but none of them have a focus on internal logistics. No one from other departments focuses on internal logistics either. Because there is not enough focus and people do not feel responsible, it is difficult to implement improvements.

3.2.2 Logistics not under control

One consequence of the problem described above is that the logistics process is not under control. Because no one focuses on it, it is not analysed and considered for optimisation. In the case of WILA, each unit manager is responsible for logistics within his or her department. This ensures that each unit organises its own logistics and as soon as an order is finished in that unit, it is placed on the shelf in the next unit. As a result, there is no overarching person in charge of logistics. Because they are separate islands, it is difficult to make improvements to the overall logistics.

3.2.3 Logistics not at the same level as manufacturing

Another consequence of the lack of focus on internal logistics is that logistics is not at the same level as machining processes. At WILA, production development is mainly focused on automating machining processes, and this is also the case at other companies. As a result, technologies for internal logistics are not at the same level as the rest of production. This makes it difficult to link the new internal logistics technologies to the machining processes at a later stage, because they are not developed equally.

3.2.4 High investments

One consequence of logistics lagging behind is the high investment required if a company wants to bridge the technology gap. Another cause for high investment is that if the process is not already optimised, an automation solution will be over-engineered to make the process work properly. Due to the lack of understanding of how to approach implementation and the risks involved in doing so, companies are discouraged from taking the step towards large investments[26].

3.2.5 Where to start

As described earlier in this research, internal logistics is a comprehensive phenomenon and can therefore be optimised in many areas. Because it can involve large investments, it makes sense to approach optimisation in stages. However, the lack of insight and control makes it difficult for companies to know where to start. As a result, projects are not started or are started in the wrong order, making the final optimisation more difficult.

3.2.6 Solution direction and requirements

The next step is to draw up a solution direction and requirements based on the problem analysis. First of all, it should be said that if companies want to improve their internal logistics, they should decide to focus on it. At most, a framework can help to facilitate the focus on internal logistics. Therefore, the chosen approach was to design a framework that focuses on the following points:

- Getting insight in internal logistics
- Reducing investment and risk
- Performing steps in the right order

On this basis, the following requirements were formulated. These requirements are therefore based on the problem analysis, but also on discussions at WILA and on the literature.

The framework should help companies to:

- Create overview in the internal logistics
- Connect logistics to current manufacturing environment
- Gain insight where to start optimizing

- Optimise step-by-step
- Prioritise steps in the right order
- Make decisions for long-term or short-term investment
- Reduce the risks of investments
- Gain insight for choosing the right solution
- Reach their goals/execute their vision

Other requirements:

- The framework should be executable without prior knowledge
- The framework must be able to evolve with changing circumstances

Based on the above requirements, a concept was developed, which is described in the following sub-section.

3.3. Concept development

The concept development is described below. This development is based on the problem analysis, the requirements, the literature review and learned lessons at WILA. This is only a description of how the development took place and not of what the concept contains. The concept development was carried out using the Research by Design approach [34] and therefore took place over a longer period of time during the research at WILA. During this time, various things were tried out and researched, which eventually led to a concept. This included information gathering, which was also part of the preliminary research, brainstorming and analysis. All with the aim of helping companies optimise their internal logistics. The result of the development is shown in Figure 26 and some drawings of the development steps are shown in Appendix A.

The optimisation of internal logistics at WILA is based on a vision of where utilisation, control and flexibility need to be improved. This is the starting point for optimisation. It was therefore decided to start the generic framework by establishing a vision for optimisation.

The next step is to establish the current state so that a company can get an overview of its internal logistics and understand what can be improved. In order to establish a good current state analysis, several analysis methods from the literature were consulted and tested in the use case at WILA. The final useful methods for this framework are described in the concept description.

The next step was to explore the steps needed to develop concrete projects from the current state that would be useful in achieving the future state. This phase is based on learned lessons at WILA. In this phase, it was hard to find the extent to which the future state should be defined at the beginning. On the one hand, it makes sense to have a clear goal to work towards. Then it is possible to take targeted preparatory steps. On the other hand, a lot may be unclear at the beginning, making it difficult to say anything meaningful about a final solution. It can happen that is started to work towards a certain goal that turns out not to be the right one. However, it is good to work towards something, which is why is decided to define an abstract future state based on conditions that the final solution should meet. Then, it is possible to work towards that future state, and the solution can then be specified further and further.

Once these steps have been taken and projects have been generated, the projects need to be compared with each other in order to make good decisions about the order of the projects that will eventually result in a roadmap. There are several ways of doing this. First is looked at the benefit/effort diagram [20], because it shows a clear trade-off between what projects cost and what they deliver. In this diagram, each project is given a value for the benefits it provides, such as cost savings, and a value for the effort it costs, such as time and money. These are then plotted against each other, as shown in Figure 24 which then makes it clear which projects are best to implement.

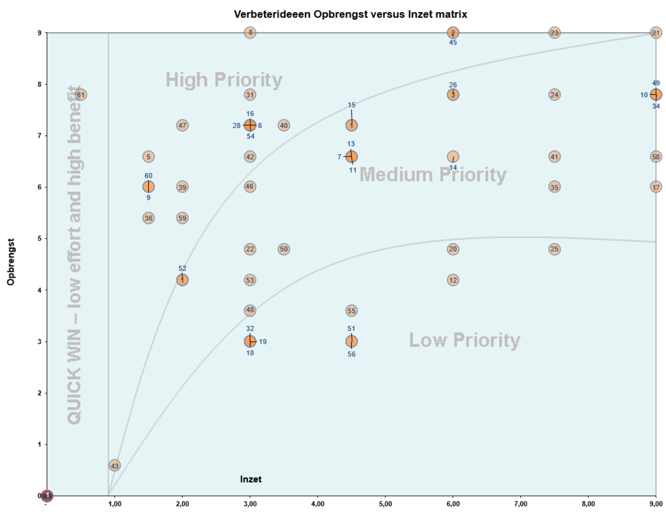

Figure 24 Benefit/effort diagram [2]

However, this tool is not appropriate for this framework because it is limited to benefits and effort, whereas the roadmap has more factors which make impact. For example, one of the reasons for the roadmap is that companies do not have an overview of how to get to the end goal. This requires several projects, but it is difficult to determine the order in which they should be carried out, so sometimes companies do not start optimizing or they start with the wrong projects. Since, the benefit/effort diagram assumes independent projects, which is not the case here, a factor representing dependency is needed.

There are also risks involved in the implementation of the projects, which are not always clear and can be an obstacle to getting started. It is therefore good to add a risk factor. In addition, the 'effort' factor has been split into 'time' and 'cost' to enable better strategic choices to be made on the basis of available resources. Also, 'benefit' has been changed to 'effect' because you are aiming for a long-term goal and not a short-term gain. Finally, 'capability' has been added to see if there is enough capacity within a company or if external help needs to be brought in. This is also important when considering which projects to undertake. A more detailed description of the factors can be found in the concept description.

This ranking of projects should lead to the roadmap. The roadmap framework is based on the outcome-oriented roadmap of [35], because this type of roadmap is suitable for a dynamic and uncertain environment. Furthermore, the approach of this roadmap is based on the vision and goals of an organisation rather than on technological characteristics. Therefore, targets are set and categorised into 'now', 'next' and 'later' [35]. For the roadmap in this framework, this is translated into projects that are categorised into 'short term', 'medium term' and 'long term'.

All of this was finally brought together in a framework, shown in Figure 26 based on the double diamond model, as shown in Figure 25, which represents a design cycle. From the vision, it diverges to the current state, where it discovers what can be improved. It then converges by defining the requirements and setting a future state. It then diverges again by generating the projects, and finally converge to the future state by ranking and executing the projects.

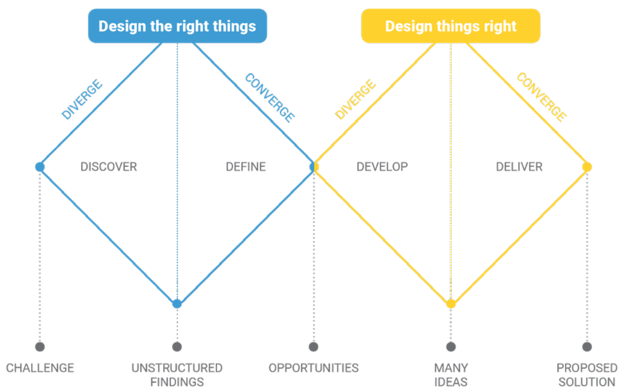

Figure 25 Double diamond model [8]

Finally, a feedback loop has been added so that the framework can move with changing conditions during the development of internal logistics.

All these developments led to the final concept. Before testing this concept, it is first described in detail in the following section.

3.4. Concept description

The concept as developed above is described below and has resulted in the framework shown in Figure 26. For each step, it describes what the step entails and why it is important.

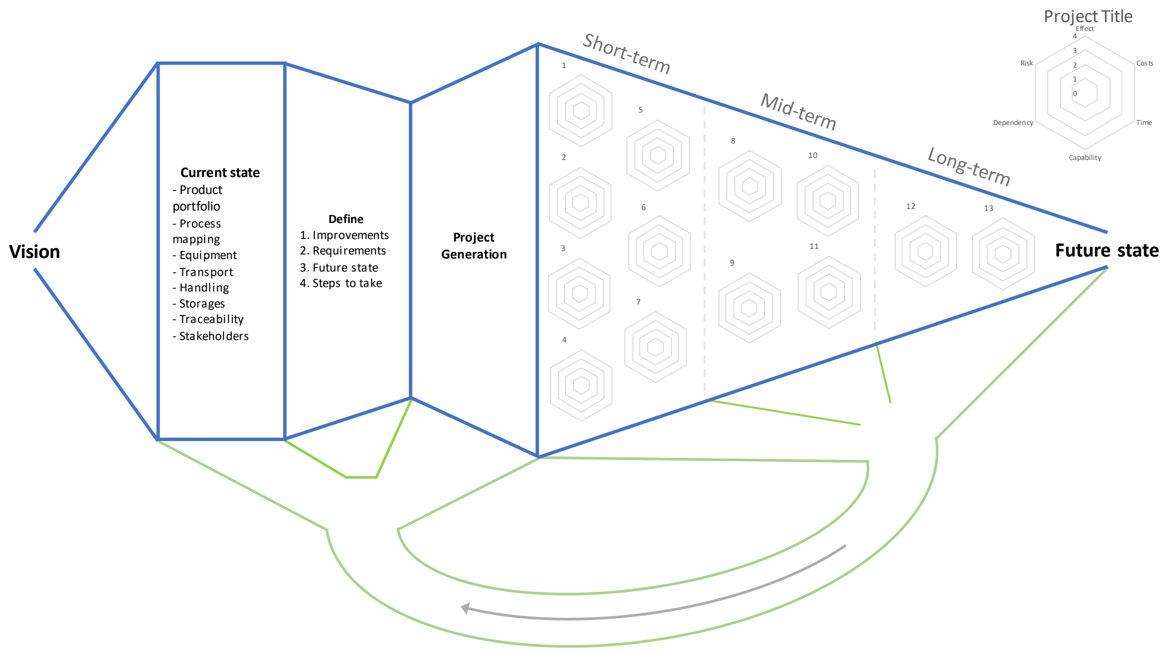

Figure 26 Framework

First, the conditions for using the framework are described. As the problem analysis showed, the first problem is that companies do not focus enough on their internal logistics. If this is the case, the use of this framework will not be the solution. In order to ensure that the framework is used in the right way, it is first important to set up a **steering committee** [36], to ensure that the framework is implemented in the right way. It is also important to have project leaders who take **ownership** of the projects [36], so that the optimisation of internal logistics can be made a success. Finally, it is also important that the **different stakeholders** [36] are involved in the development, but this will also be described in the current state analysis.

Once the above points are set, the execution of the framework can begin. Phases A to D can be processed as text and figures in a report. For phase E, an Excel file developed for this framework should be used.

3.4.1 Phase A Vision

The framework starts by asking why a company wants to optimise its internal logistics or what its vision is. This is important because it tells the company what to focus on. If there is no clear reason for optimising internal logistics, it is difficult to start optimising.

In this step, the reason or vision for the optimisation should be briefly but powerfully described. If necessary, this can be substantiated or a number of sub-objectives that the company wants to achieve can be stated. When this vision is well defined, it can be referred to during the optimisation to ensure that the optimisations add value.

As this is the first step, targeted research can be carried out in the current state and then targeted optimisation can take place.

3.4.2 Phase B Current state

Once the vision is clear, it is time to diverge and find the opportunities for optimisation. Therefore, a current state analysis is needed to explore the internal logistics. By exploring internal logistics, companies should gain insight into their process. In addition, it is good to have a baseline measurement. This can be referred to during optimisation to see the progress that has been made. From this analysis of the current state, the opportunities for improvement and the requirements for the future state should follow.

To ensure that the whole internal logistics process is involved and that the company is clear about what is going on, a comprehensive current state analysis is carried out. The idea is that if all the information is gathered once, it can be updated as needed in the future. An overview of the various steps is given first. Below that, these steps are explained in more detail below that.

1. Product portfolio
    a. Variation
    b. Dimensions
    c. Weight
    d. Vulnerability
    e. Other characteristics
2. Process mapping
    a. Which processes?
    b. Way of producing, batch, line etc.?
    c. Scheduling and routing
3. Equipment
    a. Transport
    b. Storage
    c. Unit load formation
    d. Pick and place
    e. ID and control
4. Transport
    a. Spaghetti diagram
5. Handling
    a. Amount of handlings per product
    b. Ergonomics
6. Storages
    a. Storage density
    b. Storage time
7. Traceability description
8. Stakeholders
    a. Who is involved?
    b. Responsibilities per stakeholder

Product portfolio

The current state analysis begins with an analysis of the product portfolio. The products are the key assets and for which the internal logistics must be designed. The product characteristics, together with the production process, are therefore at the forefront of the decisions that have to be made. The variation, dimensions, weight and fragility of the products must therefore be examined. Any other characteristics relevant to internal logistics should also be included in this analysis.

Process mapping

Once the product portfolio is known, the next step is to look at how it is produced. This is important to ensure that the logistics solution fits the way it is produced, by first understanding it properly. In addition, internal logistics should not interfere with production, as logistics supports production. To match the equipment to the processes, it is important to analyse the different production processes, the type of layout, the flow rate and the scheduling and routing. By mapping these components, process-based requirements can be established for the design of internal logistics.

Equipment

The next step is to get a clear picture of the current state of the different types of equipment. This is to see if it is the right equipment or if something different or better is needed. The equipment categories to be analysed are: transport, storage, unit load formation, pick and place and identification and control, as described in subchapter 2.1. By analysing the current state of the equipment, it is also possible to consider whether the new situation should be adapted to the current equipment or whether new equipment should be provided for the new situation.

Transport

The next step is to map transport movements. This is useful because it shows how products are moved around the factory. The method used to map this, is a spaghetti diagram [20]. It is possible to use weighted lines based on the number of products or orders moving along these routes. In this way, the most frequently used routes become more apparent. Once these spaghetti diagrams have been created, it is possible to examine whether the routes used are the most efficient or whether there is room for improvement.

Handling

In addition to transport movements, there is also the picking and placing of products and orders, known as handling. It is good to know what handling takes place in order to find opportunities for optimisation. To do this, it is necessary to look at the amount of handling per product and order and also at the ergonomics of these operations if they are manual. By analysing this, it is possible to see if this is the most efficient way and therefore if handling can be reduced or improved.

Storage

Storage is also relevant for analysis as it can take up valuable space. It is therefore necessary to analyse how long products are in stock and how efficiently products are stored.

The storage time of products affects the lead time and also the space required for storage. It is therefore a good idea to look at how long these times are and whether they can be reduced.

Storage efficiency can be analysed by calculating storage density. As described by [17], storage density is the volumetric space available for storage relative to the total space of the storage facility. However, in a factory there is not always one storage facility, but instead the storage is spread throughout the factory. In such cases, the aisle space is not specifically used for access to the storage area. Therefore, it may be decided to calculate the storage density as the percentage of the storage equipment used for actual storage. For example, the volume of products in relation to the total volume of the rack. By calculating the storage density, it can then be determined if and by how much it can be increased.

Traceability

The last component of internal logistics to be analysed is traceability. The data that can be obtained when traceability is good can be used, for example, for lead time analysis. In addition, good traceability is necessary for the automation of internal logistics. The above points therefore require a mapping of the extent to which products and orders are traceable and how this traceability currently works.

Stakeholders

The final step is to analyse the stakeholders. Internal logistics often involves many stakeholders and this also causes delays in development [26]. It is therefore good to be clear about who is involved and what their responsibilities are. In this way, input can be requested from the right people and developments can be presented to the right people, thus ensuring that good development takes place.

When the current state analysis is complete, there is enough information to identify improvements and requirements that can be used in Phase C.

3.4.3 Phase C Define

Phase C is created to identify what can be optimised and what the requirements are, based on the current state analysis. This, together with the vision and other information from the current state analysis, can then be used to outline a future state. Finally, is looked at what steps need to be taken to achieve this future state. This phase is the basis for project generation.

Optimisation possibilities

The first question to ask after the current state analysis is "What can be optimised? By asking this question, opportunities for improvement can be discovered. Hereby, it is important to keep the vision in mind.

To answer this question, it is therefore necessary to examine what problems occur in each category of the current state analysis and whether there are opportunities for improvement. It should also be considered whether any adjustments need to be made in production to achieve logistical improvements. It should be remembered that production output should at least remain the same or improve.

Requirements for future state

Once it is clear which areas can be optimised, the requirements can be written. There are four categories of requirements to ensure that all the necessary requirements are included and that there is a clear understanding of where the requirements are coming from. These four categories are described below.

Vision

The future state must follow from the vision, so the first category is about what requirements flow from the company's vision.

Process

The next step is to work out the conditions arising from the process. This is to ensure that the internal logistics fit well with the production process.

Optimisation

The next point is the requirements resulting from the optimisation options based on the current state analysis.

Others

Lastly, other requirements may be added. These could be, for example, strategic decisions desired by stakeholders.

Creating future state

The next step is to sketch a future state. As described in concept development, this future state must first be set up in the abstract, here conditions can be given that this future state should be reached. The requirements that this future state must meet are described above.

Steps to take

In order to get concrete projects for development towards the future state, it is good to look at what steps are needed to reach the future state. Once these have been drawn up, at creating the roadmap can then be looked at which steps need to be taken in any case, regardless of the specific solution for the future state. Steps that are less certain can then be better taken in the long term. In this way, it is possible to work towards the final solution step by step.

3.4.4 Phase D Project generation

The next phase is to generate projects. This is necessary because the problem analysis showed that companies find it difficult to decide where to start optimising and automating. By first creating projects for the different steps and then organising these projects, a roadmap can be created to help companies choose the right path.

These projects follow on from Phase C and can therefore be improvement projects or projects needed to work towards the future state. Phase D should be seen as a brainstorming phase where all sorts of projects can be conceived to create an as complete as possible overview to take internal logistics to a higher level. In order to be clear about what the projects entail and to be able to compare and place them correctly in Phase E, a number of questions have been drawn up that need to be answered for each project.

Project description

A short introduction to make it clear what the project is about.

What is the scope of the project?

Limiting the content project to ensure that the project does not become too large, for example limit to implementing one specific type of equipment for one department. Making the scope clear also ensures that the project is ranked under the right conditions.

What problems does it solve/what requirements does it address?

Identifying what the project solves or improves helps to determine the added value of the project. It can happen that something seems like a logical project, but then it solves nothing, so it has no added value.

What does it contribute to the future state?

This question also aims to identify added value. Some projects may not solve a problem directly, but they contribute to the future state and are therefore valuable. Keeping this in mind also ensures that the focus of the project remains on its contribution to the future vision.

What should be done first to implement it?

This question should take into account any other projects that need to be implemented first. This will help to identify the dependencies between different projects.

3.4.5 Phase E Roadmap

The final phase of the framework is to create the roadmap by using the projects. This involves ranking and comparing the projects. Decisions can then be made about which projects to implement and in what order. As described in the concept development, a method for ranking and comparing the projects has been developed, which is described below.

Factors

Using the information of Phase D, the projects can now be ranked according to different factors. Each project should be given a score from one to four for each factor, with one being the worst and four being the best. The factors are explained first and then how the ranking works.

Effect

Effect is the only factor that indicates what the project is delivering. It is therefore measured against cost, time, capacity and risk. With effect, it is important to consider how much a project will contribute to the vision. This is difficult to quantify this factor, so it is good to compare projects on this factor and to use that to estimate the value of the project.

Costs

Costs should be estimated before the project starts. This makes it possible to compare the costs with the effect. It also allows the different projects to be compared with each other, providing information for choosing between the different projects depending on the available resources.

Time

The time factor is similar to the cost factor. Again, it can be compared to what it delivers, and projects can be compared with each other to make decisions. The reason for separating the two is that a company may not have enough money for a major investment at a particular time, but may have enough time to carry out a project, or vice versa. By separating these factors, the information is therefore useful for making such decisions.

Capability

The third factor related to deployment is capability. With this factor, it is needed to consider whether a project can be carried out internally or whether external expertise is required to carry out the project. If external expertise is required, there are implications such as working with an external party and additional costs. At the same time, bringing in a party with more experience can shorten the duration of a project.

Dependency

An important factor in determining the order of projects is their interdependency. Certain projects are critical and must be implemented before other projects can be implemented, and therefore it is better to implement certain projects after other projects. This factor gives an indication of the interdependency and hence the order of projects, but of course decisions can be made differently, which can increase the risk of projects.

Risk

As mentioned earlier, there are risks involved in carrying out the projects and the possibility of failure can deter companies from starting them. This is because certain projects may require large investments and therefore the chances of success should be as high as possible. In addition, internal logistics depends on various factors, which creates risk, but at the same time it supports production and therefore it is crucial that things work well and therefore the risk is low. Therefore, it is good to identify what the risks of a project are and how big they are.

Ranking

In order to rank the different factors, it is necessary to assign values to the scores. To do this, the project team needs to set realistic values for each factor so that a good comparison can be made between projects. For money and time, this can be done by assigning numerical values; for effect, capacity, dependency and risk, these are textual values. An example of a value distribution is shown in Table 1.

Table 1 Value distribution

	1	2	3	4
Effect	Project contributes little to the vision	Project contributes something to the vision	Project contributes to the vision	Project is critical to achieving the vision
Costs	> € 500.000,-	€ 200.000,- - € 500.000,-	€ 50.000,- - € 200.000,-	< € 50.000,-
Time	> 50 weeks	20-50 weeks	5-20 weeks	< 5 weeks
Capability	Project should be fully outsourced	Project should be largely outsourced	Project can largely be carried out by the company itself	Project can fully be carried out by the company itself
Dependency	It is crucial that other projects are implemented first	It is better if other projects are implemented first	This project has added value for other projects	This project is crucial to the success of other projects
Risk	Chances of project success are low	Chances of project success are medium low	Chances of project success are medium high	Chances of project success are high

Once the values have been determined, the scores can be assigned to the projects in the Excel spreadsheet. This creates a six-axis radar chart per project, reflecting the given scores, as shown in Figure 27. It is important that the scores are determined with the idea that the projects will be implemented in the short term. Certain projects will cost a lot of time and money and have a high risk in the short term, while in the long term they will cost less time and money and have a lower risk. This is because certain conditions can be solved in other projects first. An example of this is shown in Figure 27 which shows the scores for the 'AGV Integration' project in the short, mid and long term. It can be seen that the project scores worse in the short term for effect, cost, dependency and risk than in the medium and long-term. By ranking the projects on the basis that they will be implemented in the short-term, a fair comparison is made and it becomes clear that the project shown is better not implemented in the short-term.

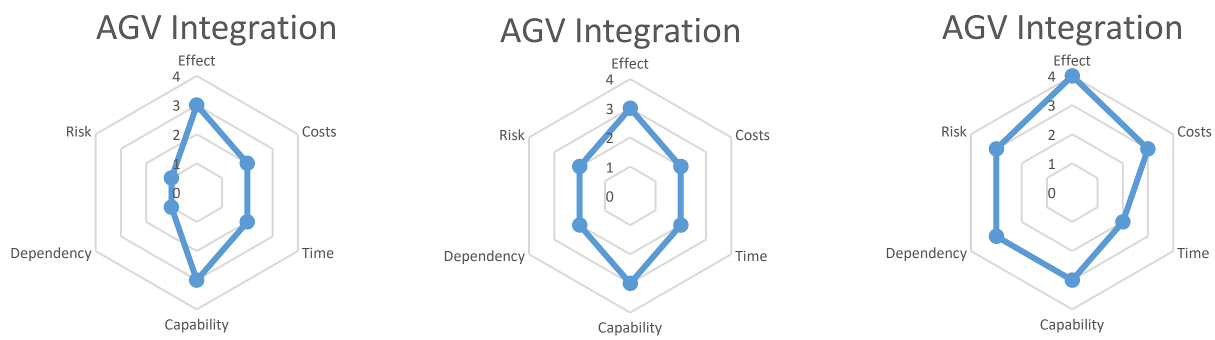

Figure 27 Radar chart AGV Integration for respectively short-term, mid-term and long-term

The next step is to indicate dependencies between particular projects by drawing arrows between successive projects. So if project A needs to run before project C, an arrow should be drawn from A to C.

Once the above steps have been completed, the roadmap can be set up by placing the projects in the funnel in the short, mid or long-term. This is where a company can use the radar charts and the dependency lines between projects to decide what its strategy will be. It makes sense to place projects with a large area on the chart in the short-term and projects with a small area in the long-term. This gives the best chance of success, and as the large area projects are implemented first, the small area projects are worked on and naturally become larger, so they can be placed in the short term. However, a company may decide otherwise for certain reasons. This framework should therefore not be seen as something that dictates decisions for companies, but rather as something that helps companies make decisions by making projects and dependencies more visible.

3.4.6 Feedback loop

The final step in the framework is the feedback loop. As internal logistics evolves, as well as other developments within a company, the circumstances in which development takes place change. Therefore, the framework needs to move with these changing circumstances in order to remain up-to-date and therefore useful. This is why the feedback loop has been added.

The feedback loop works as follows. As projects are carried out, the current state may change, new projects may emerge and the scores of certain projects may change. Therefore, after a project has been completed, the following questions should be asked

- Is there a reason to revise the current state?
- Are there new projects that can be added?
- Are there values from other projects that need to be revised?

If any of these questions are answered positive, the framework can be revised from the corresponding phase onwards. If the answer is no, the next projects can be executed.

To ensure that the framework is kept up-to-date, the entire framework should be run through after the projects in the short term have been completed. This will allow you to see what the next steps are, and a new short term will be created. This does not mean that everything has to be done from scratch, but rather that the existing content is critically reviewed and updated where necessary.

So the framework starts again and the whole framework is described. To check whether the framework works as intended, it is first evaluated against the requirements. Then the framework is tested with the users, which is described in the next chapter.

3.5. Verification of requirements

Now that the framework as a whole has been described, the next step is to check the extent to which the requirements have been met. For each requirement there has been a review of how it has been handled in the framework and whether the requirement has been satisfied.

The framework should help companies to:

Create overview in the internal logistics

The analysis of the current state should present an overview of internal logistics. However, due to the varied aspects involved, the process can be disorganized. Thus, it is important to conduct the analysis in a structured manner and keep the report well-organized. This ensures the fulfilment of the aforementioned requirement.

Connect logistics to current manufacturing environment

The process mapping and equipment analysis will reveal the status quo of the manufacturing environment and internal logistics. An assessment of whether they are on the same level or not should then be carried out, followed by an analysis of how to improve them. Once the improvements are determined based on the current analysis, they should be integrated.

Get insight for choosing the right solution

The analysis of the current state and subsequent steps will facilitate a better understanding of the current logistics. With this information and the stated vision, the optimal solution can be determined. However, to attain the best solution, prior knowledge of the available options is crucial. For this reason, users should conduct research before utilising the framework or research new solutions while using it. Nevertheless, the framework will aid in the search for the appropriate solution. In the end, finding the right solution may be hard with its continual evolution towards the optimal outcome.

Optimize step-by-step

Step-by-step optimisation should be achieved through the following. Firstly, an overview of the internal logistics will help to understand the logistics and see what needs to be done to optimise. Then, in Phase C and Phase D, these steps are defined and finally, in Phase E, these steps are executed in the right order. On a side note, users can still run too many projects at the same time, or make projects so large that the step-by-step idea is lost.

Prioritize steps in the right order

To prioritise the steps in the right order, Phase E is important. The different factors and the representation of these rankings in the radar chart should provide enough information for a project team to prioritise the steps. However, there is no universal right order, as the order depends on the company's strategy. Therefore, it should be stated that the steps should be in line with the company's strategy and therefore Phase E will help.

Get insight where to start optimizing

The rankings in Phase E should make it clear where to start optimising. This, combined with the interdependencies of the projects, should lead to the right decisions.

Make decisions for long-term or short-term investment

The factors 'cost', 'time' and 'capability' provide information on the resources required for a project. This information, when compared with the factors 'effect', 'risk' and 'dependency', should help the user to decide whether to make a long term or short term investment. In addition, the choice between short and long term investment depends mainly on the available resources and the strategy of a company.

Reduce the risks of investments

Reducing the risk of investment is a matter of the following points. Firstly, investments should be based on a well-executed analysis of the current state. Next, the different steps to achieve the goals are worked out. Finally, the investment and risk are shown in charts and a roadmap is created to make the investments in a well-thought-out order.

Reach their goals/execute their vision

The framework starts by asking why a company wants to optimise or what its vision is. This is then taken into account when developing the internal logistics. In addition, the vision is reflected by exploring the optimisation possibilities. This vision is also included in the requirements for the logistics solution. Next, during project generation, each project is asked what it contributes to the vision. Finally, the impact factor is based on the contribution to the vision. If all these steps are done well, the framework will help the company to achieve its goals.

Other requirements:

The framework should be executable without prior knowledge

The concept description should provide enough information to enable the framework to be used without the need for additional knowledge. However, it would also be beneficial to have a specific manual that could be used during the application of the framework. In addition, as mentioned above, prior knowledge of the topic would help to make informed decisions. The use case will test the ability of the framework to be used without prior knowledge.

The framework must be able to evolve with changing circumstances

To meet this requirement, a feedback loop has been incorporated. By revisiting phases B to E after a change in circumstances, the framework adapts to the new conditions. If the external situation changes, such as a shift in resources or strategy, the roadmap can be adjusted. As the rankings are not final, projects can be reorganised to suit the new situation. However, to evaluate the behaviour of the framework over a longer period of time, it needs to be tested. If the projects or internal logistics become more complicated, the framework may require modifications.

3.6. Conclusion

In conclusion, the designed solution meets almost all the requirements. The requirements that were not met are: 'The framework should help companies to get insight for choosing the right solution' and 'The framework should be executable without prior knowledge'. This is due to the fact that it is crucial to have some prior knowledge of the topic in order to execute the framework and choose the right solutions. This is now not included in the framework and therefore it should be improved, which is described in chapter 4.2. The reason why the need for prior knowledge was not included in the framework is probably due to the fact that it is designed with a research by design approach. Therefore, more was known about the subject when it was developed than outsiders will have when using this framework, resulting in the use of the wrong perspective.

All other requirements were met for several common reasons. Firstly, the framework focuses on creating insight into internal logistics with the comprehensive current state analysis. This helps to create an overview, connect logistics to the manufacturing environment and reduce the risk of investment. The framework also focuses on project generation and prioritisation. This helps to prioritise steps in the right order, to optimise step by step, to make investment decisions and to achieve the company's goals/vision. This last requirement is also met, since the framework starts with stating the vision and this is incorporated in the following steps. The last requirement that was met was that the framework should be able to evolve with changing circumstances, which is achieved through the use of the feedback loop.

It can be concluded that the framework is based on the requirements and therefore meets most of them. However, for some of the functions of the framework, it is not clear how they will work in practice, so it is debatable whether the corresponding requirements are met. For example, the requirements on prioritisation are now met in theory, but it is not known how these functions will work in practice.

Therefore, the framework should be tested with a use case to see how all the functions behave and if the requirements are still met. Such a test would also be useful to check the added value of the framework, as it is possible that it meets the requirements but is not useful in practice. In order to make these things clearer, a use case is being carried out at WILA with potential users, which is described in the next chapter. Despite the need for further validation, the early results of the framework are encouraging, as described above.

4. Use case and evaluation

In order to test how the framework can be used in practice and whether this is sufficient, the next step in the design process is carried out, which is the use case in order to get feedback on the concept. So, first this use case is carried out and thereafter the framework is evaluated based on the feedback from the use case. In this evaluation, improvements for the framework are indicated.

4.1. Use case

The user test is done by applying the framework to the use case of WILA. This is done as follows. First, the framework is filled with the information gathered during the design thinking process. This is done for phases A, B, C and D, which are explained below. Next, the framework is tested with three potential users. This is done by presenting and discussing the first four phases with them and by completing phase E with them. The main difference between the first four and the last phase is that the first four are about collecting data and carrying out development steps, whereas the last phase is about making decisions based on strategy. This is why this last phase, unlike the first four, is carried out entirely with potential users.

A complete execution of the framework would require a longer timeframe than is available in this research. Therefore, this use case is a condensed version of an actual execution of the framework to verify its proposed functionality. The condensed version excludes a comprehensive, in-depth current state analysis and not all projects have been ranked. In addition, the projects are not executed, so the feedback loop could not be tested.

4.1.1 Phase A

The reason for optimising internal logistics at WILA is to improve the control, utilisation and flexibility of the production process. The vision is to achieve a turnover of 100 million euros in five years with the current facilities.

WILA also relies on automation to maintain product supply despite staff shortages. Another reason for automation is to reduce costs in order to compete with low-wage countries.

4.1.2 Phase B

Product portfolio

WILA's product portfolio in the tooling factory consists of two types of products, namely top tools and bottom tools, as shown in Figure 28 and Figure 29. These tools are produced in thousands of variations for WILA and three white-label brands. The dimensions of the tools vary significantly, the maximum and minimum dimensions are shown in Table 2.

Table 2 Product dimensions

Dimension	Min (mm)	Max(mm)
Length	10	515
Width	20	220
Height	70	270

Figure 29 Top tools

Figure 28 Bottom tools

There are also six different tool adaptations. This makes sense because most of the product carriers are based on the product adaptations.

Lastly, the products are quite fragile. First of all, the products can corrode, which is not allowed, so they should be well preserved. In addition, the products are susceptible to scratches, which will lead to rejection.

Process mapping

The different processes are shown Figure 30 These are all the processes in the Tool that are related to the production of tooling. The colours also indicate the degree of automation for the different processes. Partial automation means that some machines in the process are automated, but not all. Therefore, each batch will differ in whether it is handled automatically or manually. The processes are divided into four different units, shown by the dashed lines.

Furthermore the different routings are added. This shows that the first half of the production process is straightforward, with some exceptions for products that are not shot-peened or bending radius grinded. The main variations in the routings therefore occur in the second half of the production process, after the semi-finished stock. Further information on routings is described under transport.

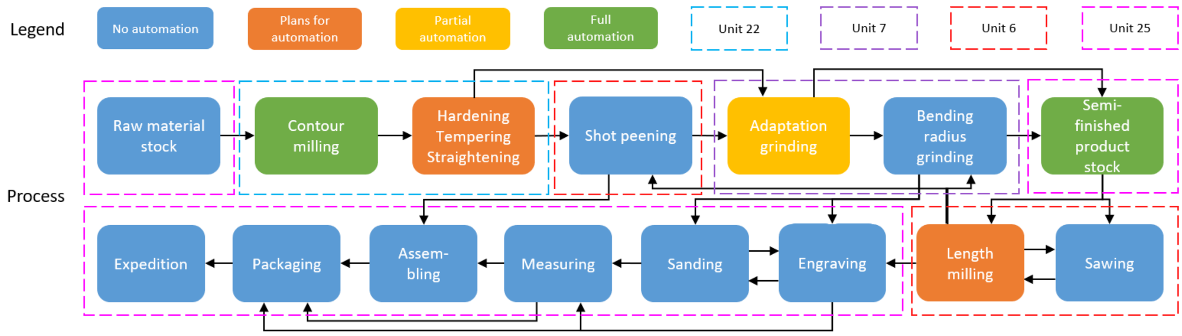

Figure 30 Process overview

The production method is batch production. For the first half, the batch size is a multiple of four, with a maximum of 44. For the second half, the batch size varies from one to twenty. The distribution of batch sizes for the second half is shown in Figure 31. As visible, most of the products have a batch size of one. This does not mean that they are all literally one, as for some products the batch size is based on customer orders and therefore the batch size is set to one in the system.

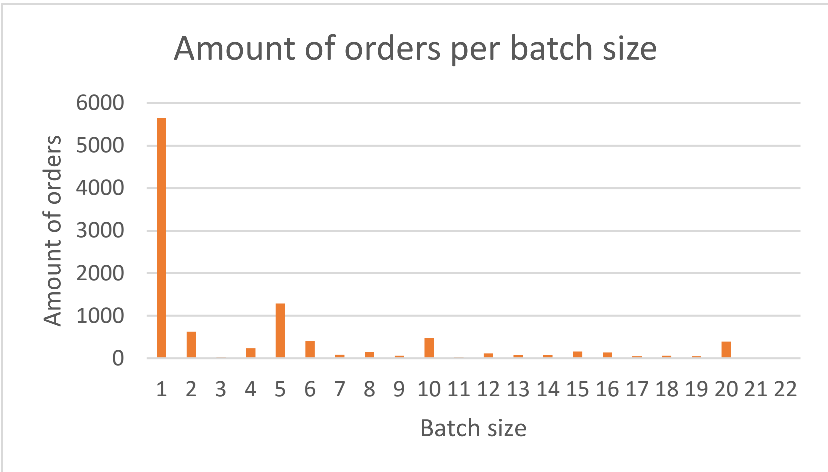

Figure 31 Distribution of batch sizes

Equipment

Transport:

- Stackers

Unit load formation

- Euro pallets
- Product carriers, these are stored in euro pallets or in vertical lift modules

Storage

- Automated storage/retrieval systems, specifically **vertical lift modules** are used as buffers at the RMC's and for the semi-finished product stock
- **Pallet dolly's** are used at the machines for storage during processing an order
- Rest of storage takes place in **racks**

Pick and place

- All the pick and place of products is done **manually,** except for handling in RMC's

ID and control

- Pallets have a paper with order number in cardholder
- Operator has list of orders to pick in ERP system
- Furthermore, barely control on internal logistics

Transport

The transport movements are captured in spaghetti diagrams. In order to create these spaghetti diagrams, a distinction was made between the process up to the semi-finished stock and the process from the semi-finished stock. This is because, as can be seen in the process map, the first half of the process is fairly uniform, whereas from the semi-finished stock there is a lot of variation in the routings. It is also clear from Figure 34 that there is a lot of variation in the routings.

As visible in the spaghetti diagrams, products do not follow the most efficient route. There are several reasons for this. Firstly, not all machines are arranged according to the sequence of the process, as shown by the blue line in Figure 33. As a result, the product has to be moved from left to right and back several times. Furthermore, the buffer storage for sawing creates extra transport distance. As the saw operators are not allowed to enter the semi-finished stock themselves, the logistics department places it in a buffer at the sawing shop and the saw operators pick it from there.

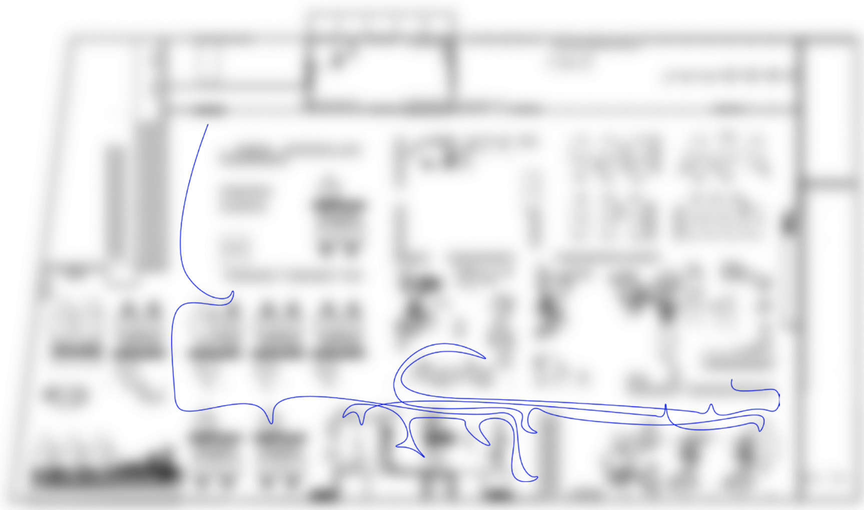

Figure 32 Spaghetti diagram first section

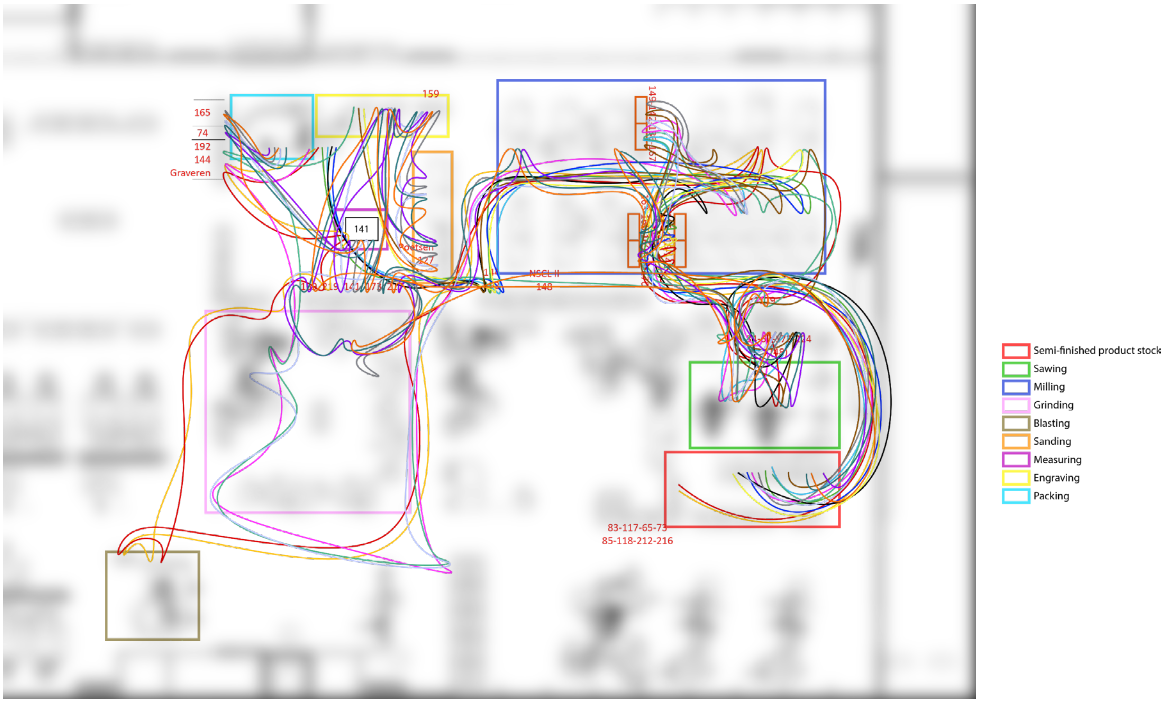

Figure 33 Spaghetti diagram second section

Handling

Handling can be seen in two ways, handling of the product carriers and handling of the products. The different steps in the handling of unit loads can be seen in Figure 35. Firstly, it shows that orders are often picked up and placed in the different storages. Secondly, this figure shows that there is a variety of product carriers used for the different processes, which makes it difficult to transport and store the products in a universal way. Furthermore, this variety of product carriers means that products have to be repacked several times, bearing in mind that this figure is a visualisation of the simplest routing. For example, Amada's products are stored in different product carriers in the semi-finished product stock, which means that they have to be handled even more.

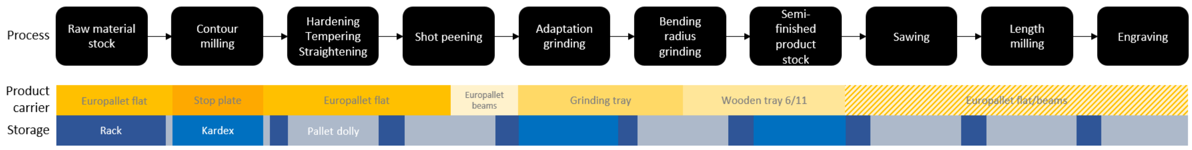

Figure 34 Overview of product carriers and storage in process

All of this product handling must be done manually, which can cause ergonomic problems. The products can weigh up to 35 kg. For products heavier than those allowed for manual picking, there is a lifting aid, but it does not work comfortably. The repetitive performance of ergonomically demanding tasks can lead to injuries.

A final point on handling concerns euro pallets. These can be used in two ways, either by placing the products loose on the pallet or by placing beams into which the products can be placed. Both methods require several operations to assemble the pallet, such as adding a top edge, protective plate, oil paper, beams and protective film. When the order is completed, the pallet must be disassembled so that the parts can be sorted and returned to the starting point. This causes a loss of time in this process.

Storage

For the storage analysis, the storage time should be analysed to see if it can be optimised. However, this data is not available at WILA. Therefore a project should be started to get this data. Looking at the storage buffers and the throughput time, it seems that the storage time could be reduced.

For the storage density, the storage buffer prior to length milling is considered because it is expected to have the lowest storage density. Therefore, this buffer has the most potential for improvement. In Figure 36 this storage buffer with dimensions is shown, it has 24 spots for a euro pallet. Due to the lack of traceability, there can only be one order on each pallet; this will be explained in the chapter on traceability. To calculate the storage density, the average batch size per segmented set is taken and multiplied by 24 to calculate the volumetric space of the products in relation to the total volumetric space. Table 3 shows the results for the most produced segmented sets. In practice, it will never happen that a rack is full of only one product. Usually it is a mix of different products, but it can be concluded that the storage density will be around 1.3% with a minimum of 0.3% and a maximum of 5.6% when the rack is full of /1 with batch size twenty.

These results are based on regular orders, client-based orders are even worse, as shown in Figure 38. This is due to the lack of traceability, as explained below.

Table 3 Storage density per segmented set

Segmented set	Storage density
/1	2,9%
/2	1,7%
/12	1,9%
/CG	0,5%
/CH	0,3%
Overall	1,3%

Figure 35 Storage rack with dimensions

Traceability

Traceability can also be seen in two ways, order traceability and product traceability. Order traceability now works as follows. The pallet with the order has a card holder with an order number, the left white paper in Figure 38. A pallet is placed in the rack that belongs to the next process in the processing sequence. Certain racks are linked to certain cost centres, as shown in Figure 37. So by looking where the order is in the process and which cost centre is the next step, the order can be found in the rack using the order number.

Figure 37 Client-based order on one euro pallet

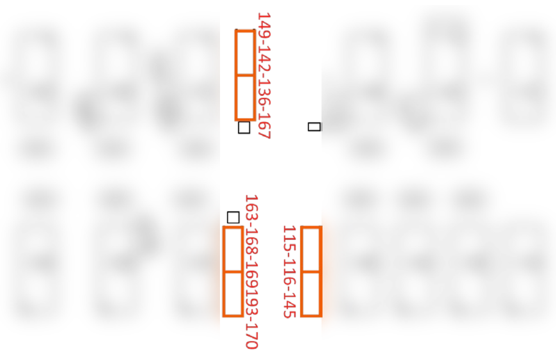

Figure 36 Cost centres and corresponding storage racks

Products are not individually traceable, so there can only be one type of product per pallet. The order number on the pallet can then be used to identify which product is on the pallet. However, there may be different sizes of the same type of product in a pallet, as in Figure 39, in which case the individual products must be identified by product knowledge or by measurement.

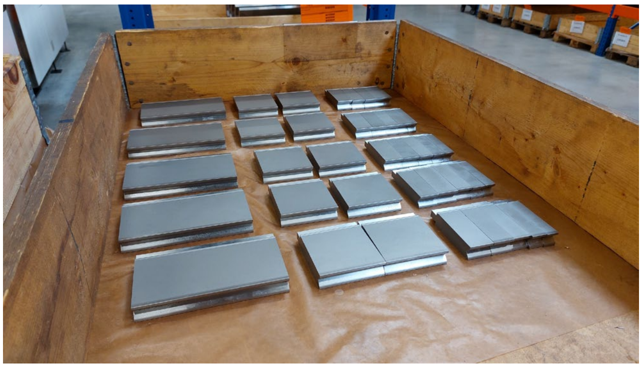

Figure 38 Different sizes of one product type on one euro pallet

The lack of traceability therefore leads to low storage density, as different products cannot be placed on the same pallet. In addition, orders cannot simply be placed on a rack as they would be lost, so racks are linked to cost centres. Again, storage space is lost compared to a situation where products can be stored flexibly. The reason for this is that certain machines are used for certain products, so as the product mix changes, not all machines are always at the same level of utilisation and therefore not all racks are fully occupied. Because they cannot be stored flexibly, more storage capacity is required than is actually needed.

Another problem is that products cannot be located quickly, therefore operators have to search for products in the racks. Some cost centres also have multiple locations where orders may be stored, so they have to search for the order in multiple locations. As a result, operators spend time searching for orders, but data on how much time this takes is not available.

Stakeholders

The different stakeholders and their responsibilities are visible in Table 4.

Table 4 Stakeholder overview

Role	Responsibilities
Director of Manufacturing and R&D	Part of steering committee and client
Production Manager	Part of steering committee and client
Manager Process Development	Part of steering committee
4 Unit Managers	Information provision They should be included in the projects regarding their unit
Planners	Information provision. Planning strategy could be change due to projects, so they should be included in these projects.
R&D Project Manager	Leading the projects and executing projects
R&D Engineers	Executing the projects
Operators	Information provision Take along in the process for integration

As visible, there are a lot of people involved in internal logistics. Since the production process is divided into four units and internal logistics connects these units, it is important to keep the production manager, the planners and the unit managers in line. Not all stakeholders will be involved in all projects, but this should be decided per project.

4.1.3 Phase C

Optimisation possibilities

The optimisation possibilities are described in the order of the current state analysis.

One optimisation from the process mapping together with the equipment is the storage buffers at the RMCs. Each RMC has its own automated storage buffer, which is needed because the supply of raw material to the RMCs is not automated. The storage buffers are therefore added to ensure that the RMC can operate 24 hours a day without a full-time operator. If the raw material supply is automated, the storage buffers could be removed or replaced, resulting in better space utilisation. It also increases flexibility by reducing the time between raw material being delivered to the RMC and the material being processed. This means that an order can be rescheduled to another machine at the last minute.

Transport distances could be reduced by replacing storage buffers or removing unnecessary storage buffers. Removing storage buffers can also reduce the number of transport movements. This optimisation will result in better space utilisation when there are fewer storage buffers. It also results in better utilisation of people, as there is less transport time.

To further improve the people utilisation, transport could be automated. However, then the first would be to improve the control of transport.

The next step is handling, where some improvements are also possible. First of all, the number of different product carriers could be reduced. This will reduce the number of handling operations and provide better opportunities for automation when transport and storage become more universal.

Another aspect of handling is ergonomics. Repeated performance of ergonomically demanding tasks can lead to injuries and should therefore be improved. Lifting aids are already in use, but they are not comfortable to use and time consuming. It would therefore be better to automate handling as much as possible. This will also contribute to the desire to make internal logistics independent of people.

The next two points relate to storage. Firstly, it is important to gain a better understanding of storage times. Once this is known, it can be decided whether it should be optimised or not. This can be done by analysing data on throughput and processing times or by using traceability. As a result, insight into storage times allows for better control. In the second place, storage density can be improved in two ways. Firstly, by creating a product carrier that stores products more efficiently than a euro pallet. Secondly, if individual products are identifiable, more products can be stored on a product carrier. However, this can increase throughput time because the different orders have to wait until they are all finished, so an optimum should be sought. Nevertheless, higher storage density leads to better space utilisation.

Identification and control is the final area for improvement. Overall, identification and control can be improved as it is at a low level in the current system. This could be done by implementing a Warehouse Management System, which would allow better control of internal logistics. Another option is to improve traceability, some of the benefits of which have already been described, but there is one more. If orders can be tracked accurately, operators will not have to search for orders, which will lead to better utilisation of people and possibly machines.

List of requirements

- Vision
  - Optimisation should lead to improvement of control, utilization and flexibility
  - The internal logistics system should be able to operate human independently
- Process
  - Solution should connect to current production environment
  - Solution should connect to future production environment
    - Products have to be positioned precisely
  - The logistics may not disturb the production process
  - The logistics should connect with batch production
  - Logistics must be flexibly organised
- Optimisation
  - The number of transport movements must be reduced
  - Transport distances must be shortened
  - The number of logistics operations must be reduced
  - Storage density must be increased
  - Products must be stored flexibly
  - Products must be traceable
  - Orders must be traceable
  - The solution must not contain any ergonomically burdensome operations
- Others
  - The solution must have support within the organisation

Future state

For now, the future state that WILA should develop towards looks like this. A flexible system that can operate independently of operators. This means that it does not matter where orders are stored or which route they are transported, but that the system itself calculates what is most efficient. The system must take into account the highest possible storage density and the shortest possible transport distances. The aim of this future state is to improve the control, utilisation and flexibility of the plant.

Steps to take

To achieve the future state described above, the first step is to improve control of the internal logistics system. This requires more insight into the process and improved traceability. In order to work towards an autonomous system, a digital infrastructure must first be created in which a Warehouse Management System can be used. The next step will be to further automate internal logistics and integrate it into the digital infrastructure.

4.1.4 Phase D

Based on Phase C, the following projects have been generated.

- Reducing transport distances by moving storage buffers
- Making orders traceable
- Making products traceable
- AGV feasibility project
- Integration of AGVs
- Development of universal product carrier
- Replacement of racks by Kardex
- Racking at the cost centres

- Eliminate storing buffer sawing
- Communication between production cell and logistics
- WMS integration
- Mapping information flows
- Automatic pick&place

Three projects are given as examples in Appendix B using the questions described in the concept description.

4.1.5 Phase E

This phase was carried out with three potential users. These were the Director of Manufacturing and R&D, the Process Development Manager, and an R&D Project Manager. They were chosen because they would be involved in setting up the roadmap if it were to be implemented in practice. The values used were agreed as shown in Table 5.

Table 5 Value distribution

	1	2	3	4
Effect	Project contributes little to the vision	Project contributes something to the vision	Project contributes to the vision	Project is critical to achieving the vision
Costs	> € 500.000,-	€ 200.000,- - € 500.000,-	€ 50.000,- - € 200.000,-	< € 50.000,-
Time	> 50 weeks	20-50 weeks	5-20 weeks	< 5 weeks
Capability	Project should be fully outsourced	Project should be largely outsourced	Project can largely be carried out by the company itself	Project can fully be carried out by the company itself
Dependency	It is crucial that other projects are implemented first	It is better if other projects are implemented first	This project has added value for other projects	This project is crucial to the success of other projects
Risk	Chances of project success are low	Chances of project success are medium low	Chances of project success are medium high	Chances of project success are high

Seven projects were ranked with these scores, resulting in the roadmaps shown in Figure 40 and Figure 41 for two of the use cases.

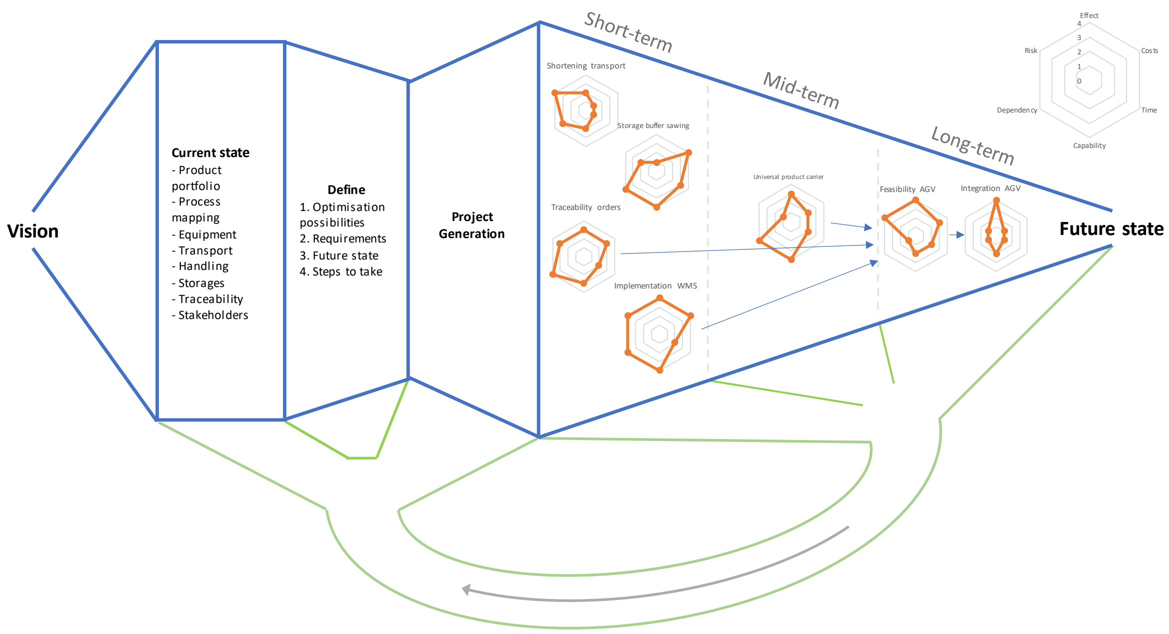

Figure 39 Use case result 1

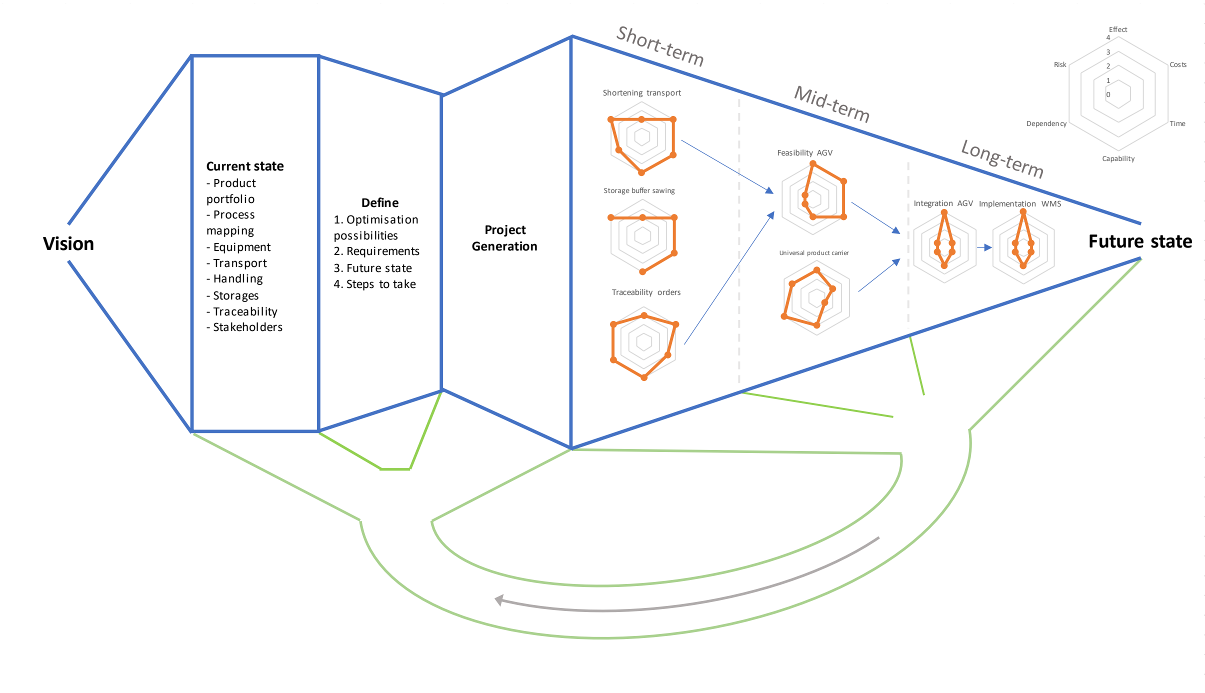

Figure 40 Use case result 2

A first remark on result 2 is that the dependency factor for 'storage buffer sawing' is missing. This is due to the fact that this project is independent and therefore the user would not give a score to this factor, because that would be unfair for comparison. This is further elaborated in chapter 4.2.5.

Another remark is that the feedback loop is not tested because it requires some projects to be executed first to see what happens when circumstances change.

4.1.6 Result

As a conclusion of this use case, a project list is set up based on the results of the frameworks.

Short-term projects:

- Shortening transport
- Storage buffer sawing
- Traceability of orders
- Implementation WMS

Mid-term projects:

- Universal product carrier
- Feasibility AGV

Long-term projects:

- Integration AGV

These results are mainly based on result 1 in Figure 40, because this roadmap is most in line with the strategy that firstly the internal logistics are optimised before they are automated. The implementation of a warehouse management system could also be seen as a automation. However, with making orders traceable, this could be directly implemented in the WMS and therefore it is good to develop this together. Furthermore, it is good to have the digital infrastructure on point before the integration of AGVs. This strokes with the strategy of result 2, but it would be harder to implement the WMS afterwards and the AGV could not be used to its full potential when the back end is not developed.

Furthermore, the feasibility research voor AGVs is placed on the mid-term instead of the long-term as in result 1. It is placed in the mid-term because than there is still time to execute other projects when it turns out that it is nog possible to implement AGVs yet. The development of a universal product carrier is placed in the mid-term too, because it does not have high priority but it has added value when automating the transport. This is an interesting result looking at the starting point of this assignment which will be elaborated in chapter 4.3. At last, this result show that before WILA can integrate AGVs, several steps have to be taken.

4.2. Evaluation and improvements

Once use case has been carried out, the final step in the design process can be completed. This is the evaluation of the concept based on the feedback gathered during the use case. This feedback is used to make improvements to the final design. Some improvements are also based on the requirements verification in chapter 3.5. First an overall evaluation will be described and then the specific feedback with its corresponding improvements will be elaborated. The order of the feedback and improvements is based on the order of the phases.

Overall, the potential users were satisfied. Most of the functions were included and the framework passed the requirements verification. In addition, the framework provides a stimulus to delve into the subject and gain insight into the process, which is positive. A problem with the comprehensive approach could be that it takes too long, resulting in stakeholders dropping out because no progress is being made. On the other hand, if this framework is to be used to build for the next five years or more, a good foundation is needed.

4.2.1 Phase A

Two things should be added to the first phase. The first addition concerns the scope of the framework. During the use case, some projects were generated that were outside the scope of this use case. For example, a project about lead time analysis, internal logistics is part of it, but it is broader than internal logistics and therefore out of scope. To avoid such situations, a clear scope should be defined at the beginning of the project. In line with this, there is confusion about some of the terms used in the use case. A list of terms and definitions should therefore be drawn up to ensure that everyone understands what is meant.

Another problem was the lack of prior knowledge about the topic, which was discovered during the requirements analysis. This was also evident in some of the discussions during the use case. Therefore, the list of definitions could already help and users should do some preliminary research to familiarise themselves with the subject.

4.2.2 Phase B

The current state analysis is already comprehensive, but one thing is missing. This is the mapping of data flows. This is needed to improve identification and control equipment and to provide a basis for the development of a digital infrastructure. Therefore, a data flow mapping method should be added to the current state analysis.

4.2.3 Phase C

The following improvement concerns the description of the future state and the steps to be taken. This improvement is already implemented in the concept and described in the concept description. In the first use case it was not properly worked out what was meant by these steps. As a result, the future state became too specific, which prevented dynamic development. Furthermore, the steps to be taken were unnecessary or equivalent to project generation. Then, together with the first potential user, it was decided to make the future state more abstract and then to describe more concretely the steps that have to be taken to reach this future state. This way there is room for development in different directions.

4.2.4 Phase D

The framework is primarily intended for use by process development engineers. However, as described, it is important to involve other stakeholders. For some stakeholders, such as operators or unit managers, such a framework may be too abstract. Therefore, it is better to involve them in certain aspects of the framework. This will be done by obtaining information from them for the analysis of the current state. But it is also possible to involve them in project generation. This could be done by presenting them with the results of the framework so far and then brainstorming with them about possible projects.

4.2.5 Phase E

Most of the feedback was on the last phase, which is logical, as it was carried out together with the potential users, and it is more abstract than the first four phases.

It was already mentioned in the concept description that it is important to rank the projects according to their current state. However, there was still some confusion about the rankings in this phase, so it is important that this is clearly emphasised and explained in this phase.

Two other feedback points were about the factors. The first is the effect factor and the other is about dependency. Effect is difficult to quantify as it is not expressed in savings or any other number but as a contribution to the future state. One option is to add key process indicators to the future state, which makes it possible to rank the effect based on improvements in key process indicators. Another option is to rank the projects relative to each other and rank the effect in this way. At the very least, this factor should be well defined to make it usable and useful.

The problem with the dependency factor was that some projects are not dependent at all, such as the removal of the storage buffer sawing. It is therefore difficult to give such a project a score on this factor. Whatever score is given, it is unfair because it is not based on anything and it can influence the roadmap when comparing the shapes of the radar charts. Leaving out the score would result in a five-axis chart or an incomplete shape, which would also be difficult to compare with the other shapes. A solution has not yet been found, so this is a recommendation for future research.

Another evaluation point about dependency is that it is still difficult to see how projects are interdependent. This became clear for example with the WMS implementation project in the use case, where one person thinks it is a starter project and the other thinks it is a final project. Both are possible, but it is not clear which is better. It was intended that the project generation questions and rankings would help, but it turns out that this is not enough for potential users. Therefore, more research is needed on the development of internal logistics to give advice on the dependency and order of projects.

The last feedback concerns the terms used in the roadmap. In the excel concept that was used, the empty charts were already placed in the roadmap and they were filled with the shapes after the projects were ranked. The next step is to replace the projects in the right term, but this was confusing as the projects were already in a term. So it is decided to place the diagrams and therefore the shapes outside the roadmap. Once the projects have been ranked, they can be placed in the desired term in the roadmap.

Another point about the terms was that the advice to place large forms in the short term and small forms in the long term could be perceived as too coercive. However, it is still an advice and projects can be placed in a different term if they wish. The framework is intended to support and guide the development of internal logistics, not as a strict guideline.

4.3. Conclusion

Once the feedback has been evaluated and the improvements to the framework have been made, it is time to evaluate the execution and results of the use case. This will show how successful the use case was and what should be improved and tested for further validation.

Firstly, it is important to note that the use case was a condensed version of the actual execution of the framework due to the available time. As a result, not all of the projects needed to optimise internal logistics at WILA have been generated. Furthermore, not all generated projects were used in the creation of the roadmap. However, some interesting conclusions can already be drawn from the results of the roadmaps and thus the framework.

The first result is that one project in the use case shows the added value of this framework. This is the 'Universal product carrier' project. This assignment started with a request from WILA to develop a universal product carrier. However, it soon became clear that other optimisations might have a greater impact than this project, and so this research was started. The use case shows that this assumption was correct, as this project is in the mid-term. So it still has value, but it is not a high priority project and it is better that other projects are done first. The use case thus proves that the framework helps companies to prioritise projects in the right order.

Another result is that different strategies are possible within the same framework. This can be seen from the placement of the 'WMS implementation' project in the roadmaps. One user placed this project in the short-term, while the other placed it in the long-term, even after the integration of AGVs. This shows two different strategies, one user using the integration of the WMS as a base for further implementation where the other user chose to implement the physical technologies first and then the digital technologies. This shows that use case proves that the framework can be a good basis for discussion. Because the users both thought about their scores and the placement of the projects and therefor they will have arguments that can be used to create the best roadmap. This shows also that the framework does not make decisions for a company, but helps to make decisions.

The 'storage buffer sawing' project in the roadmap shows that this is a stand-alone project, it does not directly contribute to the implementation of new technologies. However, it is still valuable as an optimisation and can be carried out if the resources are available. As this project will improve utilisation, it contributes to the future state and shows that implementing new technologies is not the only way to optimise internal logistics.

Another result of this and other projects is that it became clear that the dependency in the roadmap should be improved, as described in chapter 4.2.5. chapter 3.5 was concluded that the requirements for prioritization were met, but the use case thus shows the opposite. This also demonstrates the usefulness of the use case. In addition, further improvements to the framework became apparent with the execution of the use case as available, as described in chapter 4.2.

In spite of the results achieved by the execution of the use case, there are also some points of discussion about the use case. Firstly, the framework is developed with a research by design approach and the use case is a result of that. Therefore, it is questionable whether the use case is a realistic representation. It could be that a user without prior knowledge would get different results from the current state analysis. Furthermore, a different future state could be created and other projects could be generated if this were to be carried out by a real project team.

As mentioned before, this use case was a condensed version of the execution of the framework and therefore cannot be considered as a full validation. In order to fully validate this framework, several things should be improved. First of all, the framework should be fully tested in a use case. This would require a full project team and a longer timeframe. If this were the case, the results of the projects would become clear over a longer period of time and the feedback loop could also be included. Furthermore, the framework should be tested in different cases to see how it behaves in these cases and how generic the framework is. These further validations are outlined in chapter 7.2.

In conclusion, this first test has been successful because useful results have been obtained, showing the added value of this framework. Furthermore, this use case shows how the framework could be further validated. As a result, the framework can be used to create a roadmap for companies to optimise their internal logistics. When the improvements described above are integrated, the framework will work even better. This means that the design process has been successful as a solution to the problem definition has been found. However, before the framework can be said to be fully successful, more extensive testing is required.

5. Conclusion

The focus of this research was to improve the production process by optimising the internal logistics. This research was carried out for WILA and their vision is to improve their production process by focusing on control, utilisation and flexibility, therefore the following research question was stated: "How to improve the control, utilization and flexibility of a metal working plant by optimizing the internal logistics?".

In addition, it became clear that some companies are finding it difficult to implement SOTA technologies and that there is a lack of insight into their internal logistics. Due to this lack of insight, companies may underestimate the impact of implementing new technologies, making it even more difficult to optimise internal logistics. Therefore, the need for a solution that would help companies gain insight into their internal logistics and assist them with optimisation was explored.

For these reasons, a framework has been developed. This framework helps companies to gain insight into their internal logistics by performing a comprehensive current state analysis. It then explores how internal logistics can be optimised based on the company's vision. Finally, the framework helps to prioritise the generated projects and to create a roadmap that can be followed by the company. The execution of this framework is therefore the answer to the research question.

To prove that the framework is a solution to the research question as described above, the framework is first verified against the requirements. The requirements have largely been met, which means that a suitable solution has been found. To confirm this and to test how the framework works in practice, a test was carried out with a use case at WILA. This also showed that it was a good solution for the defined problem, as some valuable results were achieved. Furthermore, the potential users were enthusiastic and saw the added value of the model for future use.

The use case also showed what should be improved in the framework for further development. The main area that should be improved is the dependency of projects and thus the order in which they are best implemented. This will require further research and development, as explained in the recommendations in chapter 7. In addition, a certain level of prior knowledge is desirable for the implementation of the framework, how this could be solved is described in the evaluation in chapter 4.2.1.

A comment on this research is that it is not yet clear what the impact on control, utilisation and flexibility will be in practice, as proposed optimisation projects are not being carried out. For this reason, and to provide full assurance of the usefulness of this framework, more extensive validation is required. This should include the use of the framework over an extended period of time so that all components can be properly tested. This will also allow conclusions to be drawn as to whether the framework is delivering the desired outcome. However, based on the current use case and results, the first signs are promising.

6. Discussion

This research has been successfully completed as a solution to the problem has been found. By using the designed framework, companies can improve their production by optimizing the internal logistics. This is shown by the successful verification with the requirements and the use case at WILA. The discussion of the use case is mainly described in chapter 4.3, but is also taken into account below in short.

However, as the framework is developed with a research by design approach at WILA and validated at WILA, validations at other companies are needed to create a stronger foundation for this framework. Furthermore, the framework has not been tested with a whole project team, so it is difficult to say whether the framework is a good basis for fruitful discussions.

These further validations are also needed to demonstrate that improving internal logistics with the framework actually improves control, utilisation and flexibility of production. This conclusion is now mainly based on assumptions and literature, but has not yet been proven in practice.

One point of discussion about the design process was the stakeholder analysis. Although stakeholders were considered during development and involved in the research by design process, they were not explicitly involved in the design process. As the framework is designed to be used by stakeholders, this could be done better. This can be taken into account in future validations so that the framework can be adapted to the wishes of the stakeholders.

Nevertheless, this research provides a solid basis for further research, validation and development that will eventually allow it to be applied by companies. How this should be done is described in the next chapter.

7. Recommendations

A number of recommendations for further research and development of the framework were identified during the research. These recommendations are described below and are divided into two sections. Firstly, improvements to the framework are outlined and secondly, further validation steps are identified.

7.1. Framework improvements

First of all, it would be good to write a manual for the use of this framework. This manual will help project teams to use the framework and therefore the results will be better. This manual can also include advice, such as automation strategies.

Next, the information and communication aspect is missing from the framework. Chapter 2.3 discusses the importance of digital technologies in a state-of-the-art internal logistics system. It would therefore be a good idea to carry out a data flow and decision-making analysis and add it to the current state analysis. From there it could be included in the further development steps leading to projects for the creation of a digital infrastructure.

Chapter 1.2.2. states that on average internal logistics can cover 20% of total production costs. However, this will vary from company to company and therefore it can be useful to analyse this. This information can be used to analyse how improvements will affect this percentage and whether it can be used as a reason to carry out certain projects.

The current framework gives equal weight to all ranking factors. However, a company may decide, based on its strategy, that it wants to emphasise certain factors. Therefore, weighting factors can be added to the rankings. However, research should be carried out into how this can be implemented in the current radar charts and how it will affect the creation of the roadmap.

An important feedback from the evaluation in chapter 4.2 is the lack of clarity about the dependencies between projects. It is still difficult to rank projects in this respect and to put them in the right order. A better method should therefore be developed to clarify the dependencies between projects. One of the things that could help is to create guidelines for optimisation and automation strategies. Therefore, more research should be done on this topic in order to create useful advice that can be used to implement the framework.

The final recommendation for improving the framework is to add Key Process Indicators (KPIs). These could be used as a baseline measurement in the current state analysis. They should then be included in the feedback loop to see how much impact optimisations have on these KPIs. The KPIs can be used in two ways, to measure how production performance is improving and to measure how internal logistics is improving. Possible KPIs for internal logistics are percentage of product cost price spent on internal logistics, percentage of throughput time that product is in stock, storage density and distance travelled per product.

7.2. Further validations

As stated in the evaluation in chapter 4.3, further validations are needed to improve the framework and to claim that it can be used successfully by companies. The proposed further validations are listed below.

Firstly, a more extensive validation is needed, carried out by a real project team. This validation should include a comprehensive current state analysis, a well thought out define phase, and a project generation and roadmap creation performed with the team. In addition, the projects should be executed to test how the framework behaves over time, including the feedback loop.

Secondly, the framework is only validated with the case study at WILA. In order to create a better basis for the framework, it should also be tested in other companies. This could be done in similar companies, but it is also interesting to explore how the framework is suitable for companies in other industries.

Finally, the scope for the design process was focused on the logistics of the produced goods. It would also be interesting to test the framework for other material flows. For example, the transport of waste such as chips or the transport of machining tools. It could also be an option to integrate these flows into one framework to find combined solutions.

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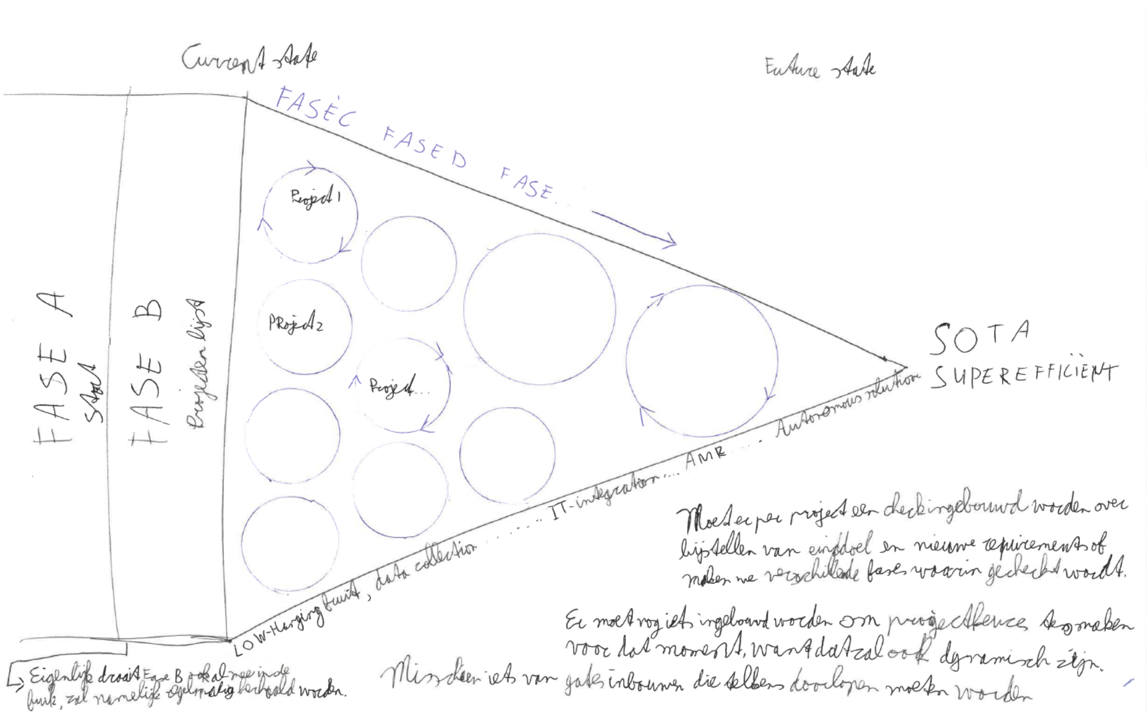
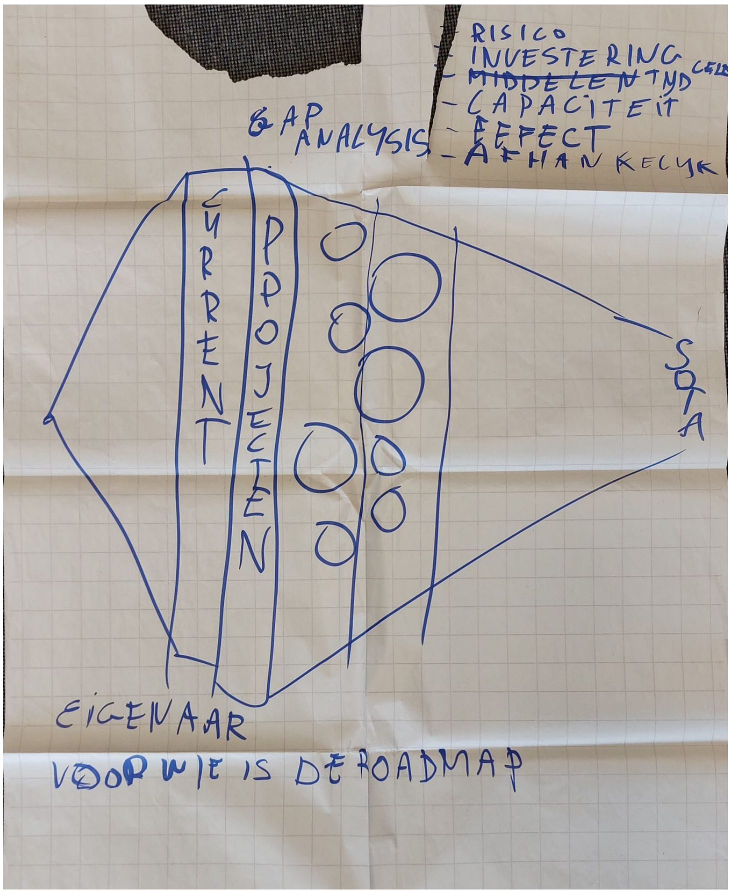
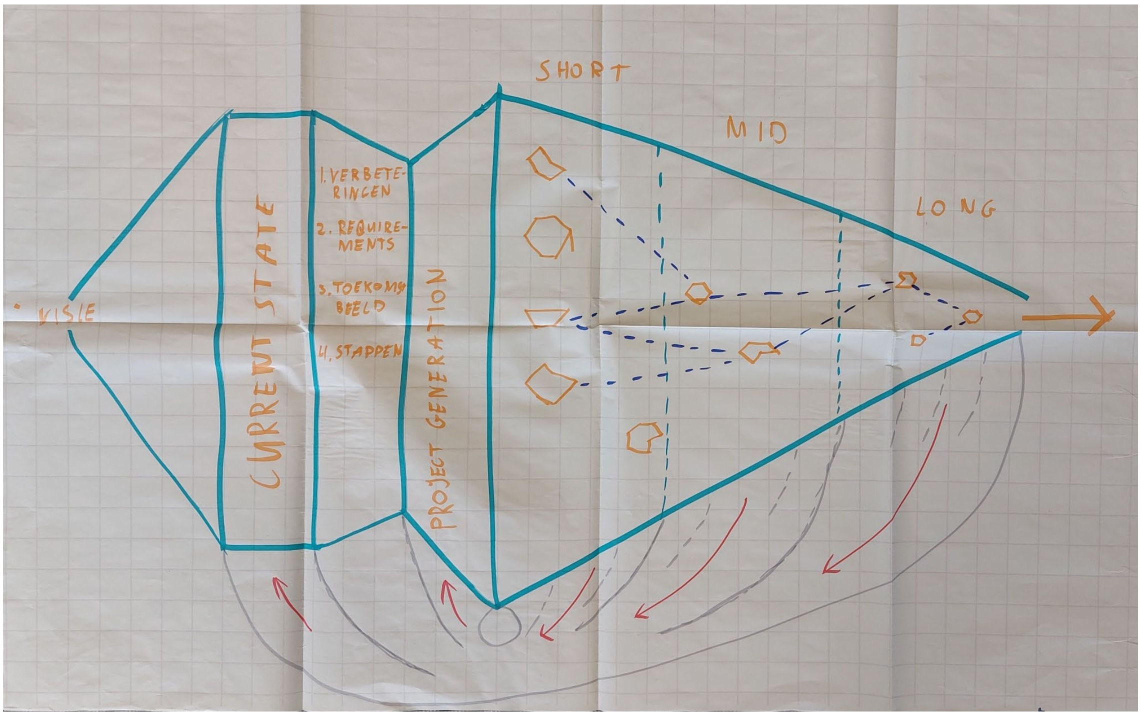
Appendix

Appendix A Development sketches






SHORT
MID
LONG
VISIE
CURRENT STATE
1. VERBETE-RINGEN
2. REQUIRE-MENTS
3. TOEKOMSTBEELD
4. STAPPEN
PROJECT GENERATION

Appendix B Project descriptions

Project

Verkorten van transportafstanden door verplaatsen storage buffers

Projectomschrijving

Door storage buffers te verplaatsen kunnen de transportafstanden verkort worden en daarmee gaat er minder tijd verloren aan het transporteren van orders.

Welke problemen lost het op / uit welke requirement komt het voort?

De transportafstanden moeten verkort worden

Wat draagt het bij aan de toekomstvisie?

De benutting wordt verhoogd, voor nu voor operators en in de toekomst voor de automatisering.

Wat is er voor nodig om het uit te voeren?

Een betere storage density zodat er minder stelling capaciteit nodig is en er daardoor ook ruimte ontstaat om met storage buffers te gaan schuiven.

Traceerbaarheid van orders zodat een order op de meest efficiënte plek kan worden neergezet in plaats van op een vaste plek.

Project

Traceerbaar maken van orders

Projectomschrijving

Een systeem ontwikkelen waardoor het duidelijk is waar orders zich bevinden in de tijd tussen twee processtappen.

Welke problemen lost het op / uit welke requirement komt het voort?

Producten moeten traceerbaar zijn.

Order density moet verhoogd worden.

Operators hoeven niet meer naar orders te zoeken

Wat draagt het bij aan de toekomstvisie?

Door orders traceerbaar te maken gaat de beheersing van de logistiek omhoog. Hierdoor hoeven operators niet meer te zoeken naar orders, waardoor de operator benutting omhoog gaat. Ook kunnen orders flexibel opgeslagen worden, waardoor er minder opslagruimte nodig is en dus de ruimte benutting verbeterd kan worden.

Ook voor een toekomstige automatisering is traceerbaarheid van orders cruciaal. Een voorbereiding daarop zou in dit project al meegenomen kunnen worden. Denk aan de integratie in het ERP-systeem.

Wat is er voor nodig om het uit te voeren?

IT-capaciteit om integratie in het ERP-systeem uit te voeren.

Project

Traceerbaar maken van producten

Projectomschrijving

Een systeem ontwikkelen waardoor elk individueel product snel geïdentificeerd kan worden.

Welke problemen lost het op / uit welke requirement komt het voort?

De storage density moet verhoogd worden.

Producten moeten flexibel opgeslagen kunnen worden.

Producten moeten traceerbaar zijn.

Wat draagt het bij aan de toekomstvisie?

Door producten traceerbaar te maken kunnen orders gecombineerd worden op één productdrager wat bij draagt aan het verbeteren van de storage density en daarmee de ruimte benutting.

Wat is er voor nodig om het uit te voeren?

IT-capaciteit om integratie in het ERP-systeem uit te voeren.