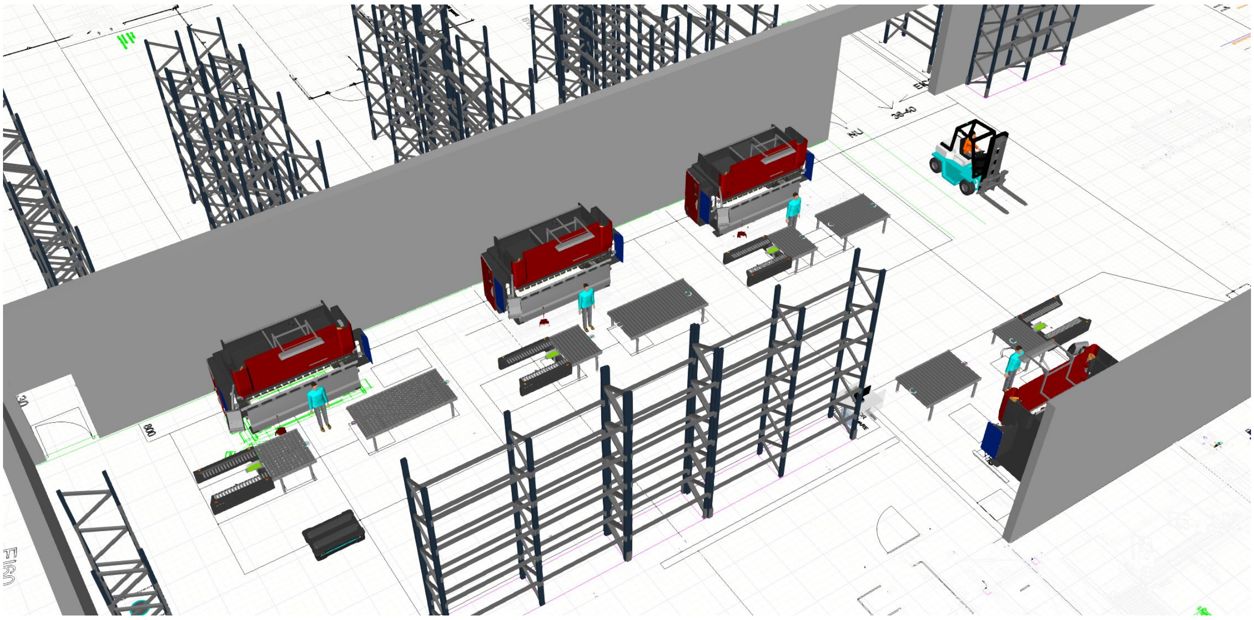
CHALMERS
UNIVERSITY OF TECHNOLOGY



Transformation of internal logistics

- with autonomous transportation

Master's thesis in Production Engineering

FILIP LARSSON & AXEL WERNESTRAND

Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

Master's thesis 2023

Transformation of internal logistics

with autonomous transportation's

Filip Larsson & Axel Wernestrand

Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
Gothenburg, Sweden 2023

Transformation of internal logistics
with autonomous transportation's
FILIP LARSSON & AXEL WERNESTRAND

Academical supervisor: Sabino Francesco Roselli, Department of Electrical Engineering
Industrial supervisor Jerry Olsson, Skandia Elevator AB
Examiner: Ebru Turanoglu Bekar, Department of Industrial and Materials Science

Master's Thesis 2023
Department of Industrial and Materials Science
Division of Production Systems
Name of research group (if applicable)
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Visualisation of the factory layout created in Visual Components.

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2023

Transformation of internal logistics
with autonomous transportation's
FILIP LARSSON & AXEL WERNESTRAND
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

Automation in internal logistics is becoming more relevant for industries today. Efficiency and cost reduction is what gets talked about the most. But automation can also be ways to improve the accuracy and reliability in the logistics processes. Manual logistics processes are usually the most accident prone processes and automation can be a good way to reduce the risks of accidents occurring, protecting the employees in the production. Autonomous Guided Vehicles (AGVs) or Autonomous Mobile Robots (AMRs) are used within many different industries for automating internal transport of material. As the name suggest an AGV requires guidance in form of sensors, wires or magnetic strips that are built into the facility. An AMR on the other hand is capable of navigating independently through the use of a software utilizing data from cameras, senors and scanners. The different vehicles receive an order, which is then processed and material is delivered to the chosen destination. The process of picking-up and delivering material varies, and is often specifically designed for the process.

This thesis covers the different aspects related to evaluating the feasibility of implementing an AGV or AMR into an small and medium-sized enterprise (SME) as a pilot project. While expanding their business the company Skandia Elevator AB (SE) is also interested in creating safer working environments, and utilizing their resources and competence for more value-adding processes as the internal transports increase. How could the implementation of an AGV or AMR not only yield benefits in terms of safety and economics, but also help increase sustainability. The process chosen in this study is the transportation of material between manual press brakes and high storage units. A repetitive work task currently performed manually by forklifts. As a backbone of the thesis the Define, Measure, Analysis, Improve and Control (DMAIC) methodology was chosen, an iterative process commonly practiced at SE. The framework was used throughout the study, except for the last two steps, Improve and Control which are beyond the scope of the project. From the results it was possible to identify that from an economical perspective the Return on investment (ROI) for this specific process will not meet the company's requirements. There are great value to be found in terms of safety along with other aspects discussed in the thesis. The findings from this thesis provide valuable insights and lessons in the implementation of this digital technology. Based on the overall assessment, it is recommended that SE continues its efforts to integrate AMR into their business operations.

Keywords: AGV, AMR, SME, DMAIC, ROI

Acknowledgements

This Master´s thesis serves as the last examination at our Master´s program Production Engineering at Chalmers University of Technology. Many people have contributed and been supportive during this project, but also through our previous courses and years at Chalmers. To all of those who have been involved we are very thankful.

The Master´s thesis have been done in collaboration with Skandia Elevator AB, who throughout the project have been very helpful. We have felt very welcomed and have had the possibility to work in their offices as well as been surrounded by great colleagues. People have shown a great interest in the project, providing us with information and volunteered in our studies. A big thank you to Jerry Olsson for the support and guidance through out the project, and for all the valuable insights. But also to Torbjörn Karlsson and Ulrica Ericsson for being available for interviews, as well as allocating time from their resources to support the project.

We would also like to thank our examiner Ebru Turanoglu Bekar and academic supervisor Sabino Francesco Rosell for their continuous support and shown interest through out the project. Moving the project forward and in the right direction by providing constructive and useful feedback, and for always being available through out the project.

Filip Larsson & Axel Wernestrand
Gothenburg, June 2023

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AGV	Automated guided vehicle
AMR	Autonomous mobile robots
CSF	Critical Success Factors
DMAIC	Define, Measure, Analyze, Improve and Control
ERP	Enterprise Resource Planning
EU-pallet	Euro-pallet
ISO	International Organization for Standardization
KPI	Key Performance Index
LIDAR	Light detection and ranging
ROI	Return on investment
SME	Small and Medium-sized Enterprise
SE	Skandia Elevator AB
TBL	Triple Bottom Line

Contents

List of Figures

List of Tables

1

Introduction

The most important aspect in any type of industry is safety. The question is therefore how can a business continue to expand and grow, without compromising the safety. A study conducted in Finland showed that 84 to 95% of fatal and serious occupational accidents in industry could be related to human error (SALMINEN & TALLBERG, 1996). Meaning that the use of automation should not only increase the productivity, but also help create a more safe working environment. Automation is often related to replacing physical repetitive work tasks by cutting operator costs, gaining efficiency, greater consistency and a faster production rate. Which is most commonly seen on assembly lines. But the knowledge of people, their dedication and talent is what ultimately makes a company successful. This should always be kept in mind when automating a process. The question is therefore not how can we replace our employees to increase efficiency, but instead how can we utilise our resources to their full potential. By simplifying and standardising processes in order to prevent human error, the talent and manpower can be used for other purposes in the business.(Evantal, 2022)

One example of repetitive work seen in many company's is in terms of logistics where material is transported back and fourth between different departments. The transport of material does not add any direct value to the customer, opposed to an assembly line. The work task are of repetitive nature, but also involves a certain risk as material in many cases is being transported close to production and employees through out the factory. A company facing this challenges as they are looking to expand is Skandia Elevator AB (SE), which currently is the leading company in Sweden when it comes to manufacturing of products and equipment for handling of grain. This Master´s thesis is done in collaboration with SE, as they are interested in evaluating if it's possible to implement Autonomous Guided Vehicles (AGVs) or Autonomous Mobile Robots (AMRs) to help handle their logistical material processes while at the same time making it a safer process. The focus is preliminary on the feeding and removal of material towards manual press brakes in the production. But kept in mind is that the company is also interested in implementing AGVs or AMRs on a broader scale in the future. In the first chapter the background is presented, along with purpose, aim and scope. To make the project more manageable considering the time horizon of approximately five months, limitations are also presented. The outline of the report is presented last, summarising the content of each chapter.

1.1 Purpose

The purpose of the project is to look at the feasibility of implementing AGVs or AMRs for material handling at SE. The company is interested in starting to transport material in smaller batches in smaller containers, compared to the EU-pallets that are used today for most of their products. It is therefore important that the system can handle smaller containers in a sufficient way to accommodate the needs of SE. The logistics department experiences the greatest number of accidents right now. The interest also has its foundation in creating a safer working environment around the manual press brakes but also creating a safer environment for logistics personal in general.

1.2 Research questions

The thesis and project's goal is to answer the following research questions:

- What impact would this implementation have on the economics, safety, efficiency, sustainability of the process?
- Are there other areas of benefits to SE in terms of investing in AGV/AMRs?
- Is it feasible to implement an AGV or AMR system in the handling of material from the press brakes to high storage units?

The results from this thesis will serve as a decision-making basis for SE, it will also be the foundation when it comes to evaluating implementation of an AGV or AMR in other segments of the factory as well.

1.3 Limitations

Due to the limited time of the project the following aspects are not included:

- Looking at other logistical flows than the manual press brakes to the high storage units. Referring to Production department means the Manual press brake department which is the only production department included in this project.
- Calculate potential cost savings based on the use of AGV or AMR for other logistical flows than the manual press brakes to high storage units

1.4 Background

There is a complex logistical flow tied to the many value adding processes within the factory. The transportation methods are of various kinds such as standing stackers combined with forklifts. Forklifts are most commonly used in the logistics flow for heavier material handling in combination with milk-runs for replenishing of smaller articles on the manufacturing lines. Today there are over 6500 articles of the type semi-finished goods and over 2500 articles which are finished goods circulating the logistics flow within the factory and reported into MONITOR G5. The packaging is in form of EU-pallets, half-pallets and plastic containers in various sizes. SE also has their own joinery where they produce different sizes pallets.

One part of the logistic flow is delivering and transporting material from the manual press brakes. The material processed in the press brakes varies in size, and is delivered in both pallets and smaller plastic bins. Today the material is delivered and removed by forklifts, and is initially collected from various places throughout the factory. As soon as an operator is finished with a batch, the finished goods need to be removed and new material needs to be added, both operations is today performed manually by a forklift operator. Larger goods are placed in EU-pallets and later stored in pallet racks, while smaller goods that can be placed in plastic containers are stored in high storage units. There are currently 4 manual press brakes, and the batch sizes varies. They are all located in the same area, and forklift operators work with feeding and removal of material closely to the press brake operators.

Since the material is delivered and removed both on pallets and in smaller plastic boxes, an AGV or AMR need to be able to function and cooperate with manual forklifts and personnel in the factory. The biggest representation of accidents today occurs in the logistics department. Apart from the safety aspect, the shuttle traffic from A to B such as transporting finished goods from the press brakes to the high storage units is a time and resource consuming process. SE therefore wants to investigate if its possible to automate the material handling in terms of finished goods from the press brakes to the high storage units, using an AGV or AMR.

SE is currently working with developing a new strategic business plan for the next upcoming five years, with the final finishing deadline to be set in the early summer of 2023. The starting point is based on the previous years, with the old strategic business plan that was finalised in 2018. By analysing and performing calculations based on this information, new financial targets have been set where the goal is to have a growth resulting in a total turnover of 500 MSEK at the end of year 2028. In order to achieve this the volume of total number of machines sold need to be increased from 2800 to roughly 4000. Where one machine includes all the different components that make up a complete grain handling system. However larger grain handling systems can include several machines.

SE wants to grow in a smart way, meaning to find cost effective solutions through automation. Not only buying new capacity in terms of labour and machines, but to continue working with existing processes and develop them as far as possible. The potential implementation of AGVs or AMRs is therefore one of many steps in terms of digital technology that will help the company reach their goals. This project is part of a bigger vision where the company in the future is interested in the possibility of utilizing a complete fleet of AGVs or AMRs performing multiple tasks. Not only in terms of logistics from the press brakes to the high storage units, but throughout the whole factory. The project will help SE gain understanding of their current degree of maturity, what is needed to carry out a successfully implementation on a small scale project, and what is needed in the future to upscale.

1.5 Thesis outline

Chapter 1 - **Introduction:** In the first chapter the company the Master´s thesis is done in collaboration with is presented together with an introduction to the project. The purpose of introduction is to define and help the reader understand the purpose of the Master´s thesis.

Chapter 2 - **Theory background:** In the second chapter the theory that is used help identify the different characteristics of the project is presented.

Chapter 3 - **Methods:** The third chapter presents the framework that is the foundation of the project. A long with how quantitative and qualitative studies will be conducted throughout the project in order to collect data.

Chapter 4 - **Results:** In the fourth chapter the results of the project are presented.

Chapter 5 - **Discussion:** The fifth chapter discusses the process of the project, how well the project goals have been fulfilled and suggestions for SE on the future implementation.

Chapter 6 - **Conclusion:** The last chapter is conclusion which summarises the Master´s thesis and the project as a whole.

2 Theoretical background

In the theoretical background the theory of the Master´s thesis is introduced such as the concept of an AGV or AMR, the many characteristics tied the technology and what differentiates an AGV from an AMR. General guidelines in terms of safety requirements are also described a long with limiting factors in terms of implementation.

2.1 Material handling

Material handling refers to the process of moving material and products to different locations in the production and warehouse. Material handling covers both the actual transport of goods, but also the containers used to move the goods. Today most of the material handling is carried out by forklifts transporting pallets, if smaller containers are used they stored inside of pallets and therefore still being transported by forklifts. Milk-run trains are used to a certain extent, for replenishing of an assembly area in the factory similar to a production line. The use of AGVs or AMRs could therefore help reduce the total number of manually operated trucks needed in the future.

2.2 The concept of AGV

Today its common practice for companies to work with continuous improvements and the lean philosophy of reducing waste and non-value adding activities, while maximising the customer value. One example of the most common non-value adding activity is the internal transportation of material, as it does not add any direct value to the product and customer. There is therefore a lot to be gained by improving the flow efficiency in the factory and distribution of material. By implementing AGVs its possible to reduce the non-value adding activities by improving the logistics of internal handling (Correia et al., 2020).

The purpose of an AGV is to transport materials and goods autonomously. Meaning that in terms of logistics such as warehouses, manufacturing facilities etc. the AGV can operate by itself using guidance. This type of solution is increasing in popularity, since it's possible to automate manual tasks that are of a repetitive nature. The AGVs also allow for good visibility of the material flow, along with reducing the risks of site downtime (Toyota, 2023). As well as increasing the tractability.

2.3 Characteristics of AGVs

There are important characteristics of AGVs such as pathing (i.e., the route the AGV travels between different locations), guidance (i.e., how the AGV is able to navigate and guide itself), managing traffic (i.e., how traffic is managed and the possibility of deadlocks occurring), battery (i.e., characteristics of the batteries used in AGVs), failure (i.e., potential breakdowns of the AGVs), and transport of load (i.e., how different AGVs are capable of different loads). The definitions of these characteristics are explained in the following paragraphs.

Pathing

One of the first problems encountered when introducing AGVs to manufacturing, is how well does the current design layout in terms of logistics support AGVs. A first good step is to create a flowchart to understand how material is handled between departments. Using figures such as for example rectangles connected by arrows, to visualize the order of the flowchart. Its also possible to create a flow path model, where pickup and delivery stations are referred to as *nodes*, which are connected by *arcs*. The arc therefore determines the path the AGV travels between the two nodes. (Le-Anh & De Koster, 2006).

The purpose of a material flow path layout is to connect fixed structures such as machines and stations. The flow path allows to asses the performance of the system, due to factors such as the total number of vehicles required and their transportation time. As described by (Vis, 2006) there are various ways in which the flow path can be designed. In our case it would be designed *"considering the layout of the facility and the location of pick-up and delivery points as input factors"*. Thereby creating a route where the nodes represent the pickup and delivery point which are fixed, and the arc being the route (Vis, 2006). In this case we are only looking at material handling between two stations, therefore there it's not a connected network. However, in the future the company want to have the possibility of expanding into a network, and further implement the use of AGVs within the factory.

Arcs can either be unidirectional meaning vehicles can only travel in one direction, therefore it's easier to manage since there is no oncoming traffic. Or they can be bidirectional meaning vehicles can travel both directions. Where the advantage is that is possible to reduce the traveling distance by making short-cuts. By combining the two types it's possible to have multiple lane guide paths, meaning one aisle can consist of opposite traffic flows. The direction of travel is chosen based on reducing the travel time of vehicles and the ability to access all delivery and pick-up points within the network. (Vis, 2006)

In this case a material flow map will first be created to map out how material is transported between the different departments, what steps are involved in the process. In order to illustrate the different path ways and how material is transported the factory layout will be used as a background, which already has all the structures such as press brakes and high storage units in place with the right dimensions. Its then possible to add the different routes on top of the layout, and highlight them with different colours.

Guidance

There are many different methods and technologies for navigation and guiding of the AGV vehicles. The most common methods are guidance made by laser, magnetic tape, or magnetic spots. (agvnetwork, 2022b) Laser guidance most commonly use reflectors which are mounted on the walls at known locations. The AGV then sends out lasers that bounce back from the reflectors and the AGV can calculate where in the room it is positioned. (agvnetwork, 2022b).

Magnetic tape guidance works with magnetic strips that gets placed out which the AGV then can follow using antennas placed under the vehicle. Magnetic spots can also be an option very similar to magnetic strips. Instead of magnetic tape small magnets are placed out in the floor creating a path for the AGV to follow. Or acting as reference points in accordance with a CAD map that the AGV follows. (agvnetwork, 2022b) All the methods above can also be used in combination with each other. In large open areas laser reflectors can be used but in places where there is limited space or need for even higher accuracy, magnetic strips or spots can be used. (Ahnell & Rosengren, 2021)

Managing traffic

Two of the main concerns when managing an AGV system is the risk of potential collisions and deadlocks. By utilizing sensors it's possible to avoid collisions, this also allows for the AGV to some extent deviate from its original path and be able to return safely without causing a collision. But as mentioned the AGV is most commonly only designed to follow a designated path, compared to an AMR which will be described later in the Section 2.4.Deadlocks most commonly occur in a part of the plant that is geometrically no fit to accommodate two vehicles that are moving in opposite direction of each other at the same time, thereby forcing a stop. If this occurs in for example a small aisle, manual intervention may be necessary to solve it. Another area where deadlocks are commonly seen is when material is being picked-up or delivered. If having a high storage unit capable of directly delivering and picking up material from the AGV without human interaction, the system must know in which order to prioritize delivery and pick-up. If a loaded AGV enters the storage unit, and a delivery has been prepared by the high-storage unit instead of pick-up. Then a deadlock can occur if another AGV is already in line, and the storage unit is not capable of handling the material that is to be delivered. This needs to be avoided, since it has a negative relation to the performance. Suitable methods therefore need to be used to avoid this (Vis, 2006) Meaning the storage system and AGVs needs to be able to communicate efficiently.

Battery

The batteries usually used in AGVs are Lithium-ion batteries which can quickly be charged up. The battery life very much depends on the AGV type, the environment, and the payload weight. But usually, a single charge can last 8-14 hours. Depending on how the AGV system solution is set up, there is possibility to achieve 24/7 operation depending on how many AGVs are used, operation time on a single charge, charging station configuration etc. Charging of the batteries can be done in different ways. The traditional way is that the AGV docks into a charging station making it unusable during charging. There are other solutions which integrate inductive charging plates in the floor which can charge the AGV if it travels or is inactive in a certain area. (agvnetwork, 2023)
Another type of battery commonly used in regular forklifts are lead batteries. These batteries require careful maintenance and the personnel responsible for charging should undergo training and be instructed about the potential risks. This is because the batteries contain sulfuric acid which is caustic. When charging the batteries release hydrogen and oxygen, when these two mix or with air explosive gas is produced which is highly explosive and flammable. Its therefore important to minimise the risk of sparks and charge the battery in a well ventilated area. To prevent this protective equipment should be available, its also possible to utilize automatic water refilling of the batteries.(Arbetsmiljöverket, 1988)

Failure

In order to reduce the costs that are associated with potential downtime of AGVs, it's important to consider maintenance strategies and failure management to ensure a high availability (Yan et al., 2018). An organisation need to constantly monitor the AGV system and intervene in case of an operational failure. This can range from just resetting the AGV or in the case of a deadlock as described by (Vis, 2006), it may be necessary to manually move the AGV. If a failure occurs and the AGV is in need of manual assistance, it's important to follow up why the incident occurred and how it can be prevented. But it's also possible to equip the AGV to an extent where it to some degree can better avoid accidents, but also recover from failures independently. (Fragapane et al., 2021)

Transport of load

The type of load the AGV can carry very much depend on what type of AGV it is. There are many different models ranging from small AGVs which are designed to carry smaller boxes to larger forklift AGVs which can handle EU-pallets or special designed heavy payload AGVs which handle large metal components that could weight up to 450 tons (MAX AGV, 20223). One of the most common AGVs is the regular forklift which have been converted. Many warehouses transport materials packaged in EU-pallets and regular forklifts are both in terms of size of load but also weight. There exist solutions for almost all types of payloads and there are a lot of companies that will offer custom solutions, either through customisation of their existing models or completely new design.

2.4 Classifying AGVs

This section will cover different types of AGVs and what differences they have. It will also cover the topic of fleet management and how a fleet of AGVs are controlled.

AGVs and AMRs

The purpose of AGVs and AMRs are to both to automate internal transportation of material. A common misconception are that they both function in the same way. When distinguishing between the two, the main difference is how they navigate. An AGV is based mainly on programming and requires guidance from sensors, wires and magnetic strips. Therefore also requiring to update the facility in order to support the AGV, not only is it expensive but it could potentially result in disturbances in production. This also means that if an AGV is to detect an obstacle in front, its not capable of navigating around it, but instead is forced to stop until the obstacle has been removed. Compared to an AGV an AMR does not require the same guidance, as it uses a software to construct maps either on-site or by pre-loading drawings of the facility it can then compare the real environment to the existing 3D-map. By using simple positions on the map it can generate the most direct path. To identify and locate its surroundings the AMR utilizes data from cameras, sensors and laser scanners combined with sophisticated software. Thereby working autonomously and capable of navigating around obstacles by itself (MIR, 2023)

An AMR is more flexible as its not required to follow a predetermined path, compared to an AGV that often are limited to performing the same tasks through its life as changes are too expensive. With the AMR its possible to only apply changes in the software in order for different tasks to be performed. AMRs are also capable of prioritising different orders and tasks, based on position and availability. Over time AGVs can become a constraint for companies striving towards more agile manufacturing and logistics, as it AMRs can be adapted to serve different purposes. In terms of costs AGVS are typically more expensive compared to AMRs as they require additional hardware. Another important aspect is that AMRs can be utilized almost immediately and bring efficiency (MIR, 2023)

Different types of AGVs

In order to distinguish between the many different types of AGVs, they are often separate into three categories. Unit load AGvs, forklift automatic AGVs and tugger AGVs. As the name indicates, unit load AGVs deals with heavy single unit objects often placed on a pallet. (6 River Systems, 2019) For example steel cylinders, steel sheets or other items that are commonly used over a short period of time with a high frequency (Hovair Systems, 2023). The second one is forklift AGVs, which are the most commonly used, and serves the same purpose as a regular forklift (6 River Systems, 2019). Where its easy to transport material between shelves or transporting pallets thanks to the variety of different forks, tilting, telescoping etc (Hovair Systems, 2023). The third one is known as towing or tugger AGVs, and pulls one or multiple load carrying units behind them. Suitable for heavy loads that are to be transported over a longer distance, often with multiple pick-up or drop-off points a long the way (6 River Systems, 2019).

Fleet management

A fleet management system is essential when multiple AGVs are operating in the same space and also within the same type of orders and work tasks. A fleet management system helps optimizing pathing and order execution. It ensures AGVs do not interfere with each other and optimises the way work orders are carried out by the different AGV units in the system. (Hažík et al., 2022)

2.5 General guidelines for safety requirements of AGVs

There exist multiple guidelines for safety regarding industrial forklift and vehicles and the same apply for AGVs. In the EU there is the ISO 3691-4:2020 standard which determine safety requirements and verification. And Part 4 specifically focuses on automatic/autonomous vehicles. In the US there is the ANSI/ITSDF B56.5-2019 standards. (ANSI, 2019) Both these standards are not obligations and do not have to be followed but are rather guidelines. (agvnetwork, 2022a)

There are many different types of safety systems that can be put in place on AGVs. Many which also exist on regular forklift and forklifts. These can be things such as warning lights like a blue spotlight or audible warnings from speakers. Bluespot lights are commonly used on regular forklifts operated by humans. Its function is to alert nearby people of the forklifts presence. It does this by illuminating a blue spot on the ground a few meters away from the forklift. (Tralert, 2023) Most AGVs are also equipped with laser or sonar sensors and many times both which can detect obstacles and people in their path and adjust the speed or emergency brake if necessary to avoid contact.

The AGV has different zones in place which will cause the AGV to act accordingly. And with the use of laser systems the AGV can sense objects and which proximity zones the obstacle is located in. For an example if the furthest away zone is entered by an moving obstacle warning sounds are used, next step is speed reduction and finally emergency stop will be performed if the obstacle comes to close. Special zones can also be created in the map of the warehouse where extra caution is needed, and the speed will be reduced when the AGV enters this zone. Examples of this could be when a operator crosswalks in the warehouse. Physical emergency stops buttons should also be available within reach on the AGV. The AGV can also be protected with bumpers etc which ensure the integrity and safety of the AGV if a collision would happen regardless of all the safety systems in place. The AGV can also have systems in place which adjust all the parameters for speed adjustment and emergency stops accordingly to its current payload. Because emergency stopping with 200kg of payload will be very different from a 1000kg payload.

2.6 Literature review

Research that are of interest for this project such as *Implementing an AGV system to transport finished goods to the warehouse* written by (Correia et al., 2020) shows that the first step is to analyse the value-adding and non-value adding activities. The different movements can be identified with a spaghetti diagram, its the possible to eliminate certain motions and increase the productivity. Since this was a newly designed system, it also required to calculate the number of required number of AGVs a long with picking and delivery stations. (Correia et al., 2020) Other research also shows the challenges associated with implementation in a more complex setting. The article *Autonomous mobile robot technology for supplying assembly lines in the automotive industry* written by (Čech et al., 2020) discusses the lack of experience when it comes to the implementation of AMRs as a larger fleet.

The importance of assessing the current available technologies and how criteria must always be based on specific needs. And the important factor of capacity calculations, fleed size and traffic load (Čech et al., 2020), similar to what was mentioned by Correia.N et al. An article based on case studies named *Challenges in the introduction of AGVs in production lines: Case studies in the automotive industry* written by (Hrušecká et al., 2019) emphasise the need of processing large amount of data in order to understand and design logistical processes, a long with model testing to find the best alternative. First setting critical success factors (CSFs) which must be fulfilled before the implementation, and then key performance indicators (KPIs) to follow up and for the company to receive feedback on potential improvements. The challenge is to determine the relations that are to be set between the CSFs and KPIs in the material handling area. (Hrušecká et al., 2019)

3

Methods

This section will cover the methods used in the thesis. The Define, Measure, Analyze, Improve, Control (DMAIC) will be used as an reference methodology. Quantitative study covers how data was retrieved from the Enterprise Resource Planner (ERP) and also how a stopwatch study was conducted to measure the current material transport times for a certain process. The qualitative study covers how soft data which was gathered in through the creation of interviews and study visits. The triple bottom line of sustainability which is the model the discussion will be based upon will also be covered.

3.1 DMAIC

The method used for most projects at SE is the Define, Measure, Analyze, Improve, Control (DMAIC) method. (Lars & Folke, 2017). This method will also be the foundation of this project. The DMAIC model consists of five different steps. The DMAIC method also has different gates which are critical points in the project that determine if the project should continue, pause or be shut down. As seen in figure 3.1 its a iterative framework where the steps are repeated in order to improve the process.
The steps are:

- Define

The define step includes defining the problem at hand. This includes the scope of the problem, aim and goals and also conclusions from similar past projects which could have valuable information. The defined stage also includes a risk analysis and the identifying stakeholders like customers and their expectations. A time plan also needs to be created and what resources the project will require.

- Measure

The measure step is all about finding and collecting information about the project. Identifying critical factors for the success of the project and also connecting these to both stakeholders and the process.

- Analyse

The analyse step focuses on the data and information gathered in the measure phase and conclusions are drawn on possible causes for problems etc. This can be done through cause-and-effect diagrams or process map analysis.

- Improve

This step is where solutions are created to the problem. The effect of the solution on stakeholders should also be identified. The solutions should be tested and verified and also potential risks should be identified. In the end of the phase one solution should have been chosen.

- Control

The control step is verifying and securing that the goal and aim have been met. Also, a plan is created for follow-up and control. This plan also takes in consideration the carrying over of the project to the production unit and hand over of the responsibility. Lastly it is verified if the desired outcome was met and the goals and aims were satisfied

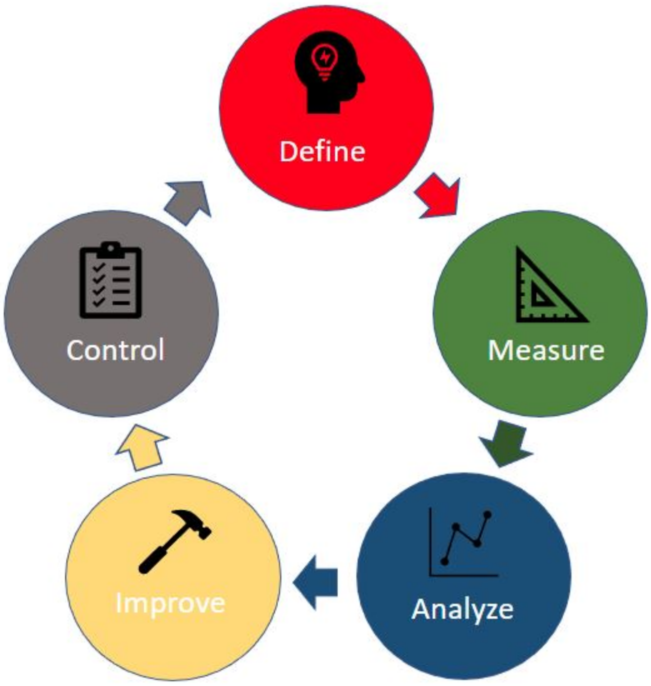


Figure 3.1: DMAIC model adapted from (Loebick, 2022)

The final two steps, Improve and Control, are not included in this thesis as they are not aligned with the thesis's aim and objective. This thesis serves as a preliminary study and analysis for SE rather than a project's development and implementation, rendering the last two DMAIC steps irrelevant. If SE chooses to move forward with the findings from the thesis, they will subsequently undertake these steps.

3.2 Quantitative data collection and analysis

The Quantitative data collection and analysis section covers how the measurable data which will be gathered in during the thesis. This includes data which will be provided by the ERP system at SE, The production simulation software used to simulate a possible future AMR solution and a stopwatch time study.

3.2.1 MONITOR G5

At SE they use an ERP-system called MONITOR G5(Monitor ERP, 2023) which handles all aspects of their organisation from order handling, to economics, to the internal logistics. MONITOR G5is a very powerful tool where customized queries tables can be created which only have the desired information and nothing else. Every action performed in MONITOR G5is timestamped and stored and can be brought up at a later stage. Therefore it is relatively easy to gather historical data.

MONITOR G5will be used extensively in this project to gather quantitative data to analyse the material flow from the manual press brakes to the storage units in the warehouse. Time and process data which is not possible to get by using MONITOR G5will be collected by studying the materials handling process in real time using stopwatch studies.

3.2.2 Production simulation software

First a model will built as a representation of the current system, which is similar but much simpler. The purpose of the model is to be able to analyse and predict what possible changes could be done to the current system. Since the model will be used to experiment upon, its important to find a balance between how detailed it should be to resemble the real system but making changes and interpreting data should still be possible. A good approach is to increase the complexity of the model and scale it over time. The model also needs to be validated by comparing the output of the model to the real system (Anu, 1997).

After the modeling is done and represents the real system, its possible to further simulate and try out changes to the system. By changing the configurations, how will the performance of the system change. By simulating in advance before applying changes to the real system, its possible to predict possible failure, bottlenecks and trying to optimize the system (Anu, 1997). For this project the simulation of production will serve two purposes. The first being to give a visual representation of what the future could look like and how AGVs could be implemented into the current production flow. The second one is to allow for calculations such as how many trips is required based on a certain output, how long will the battery last, how many AGVs are needed etc. The software used in this project will be Visual Components, see Section 3.2.2.

Visual Components is a production/factory simulation software which is a powerful tool for creating visual models of production simulations. This is the simulation software that will be used in this thesis. The program has a large 3D components library from which parts and machines can be placed out in an environment to create the desired production layout. The existing catalog in Visual components has products from many well known brands already preinstalled. (Visual Components, 2023) Both authors in this project have previous experience and knowledge of Visual Components and this is one of the reasons why this program was chosen for this thesis work.

Very complex and real like simulations can be created by setting up advanced real life behaviour for different process parameters such as setup time, breakdowns, maintenance and much more. The analysis capabilities of the program are extensive and can be used for optimizing and improving production flows. (Visual Components, 2023)
The latest version of Visual Components (4.6 Professional) have modules for AGV/AMR traffic simulation which is relevant for this thesis and thus this version of the software will be used for simulating the material flow with an AGV solution which would replace the existing finished goods traffic from the manual press brake machines out to the HISS warehouse position.

3.2.3 Stopwatch time study

Stopwatch time study is a popular work measurement method which have been used for a very long time. The goal is to measure the time it takes for an qualified operator to finish a certain process working at normal performance speed. (Zandin, 2001b) Stopwatch studies can be performed using different types of time measure devices. Both mechanical and digital. The stopwatch studies done in this project will use a regular smartphone for taking the time which will be a sufficient tool for the task.

When selecting the operator performing measurements in the time study it is desired that the operator is well trained and has experience of the task. The operator shall work at an acceptable rate and also follow the correct methods. (Zandin, 2001b)

Before a stopwatch time study is conducted, the first step is to determine the purpose. In this case we want to identify how much time is spent on transporting material with a forklift that is to be stored in the high storage units in the warehouse which are described in Section 4.3.1. In order to compare it to a simulation in Visual Components of an AGV carrying out the same task. The next step is to define the objective of the study, which is to measure the transportation time from press brakes to T11, and from T11 to HISS-IN. In order to determine this we need to identify what activities to include into the measurements. A stop watch study is most commonly used to identify value adding and non-value adding activities. (Zandin, 2001a)

Its also possible to calculate the number of observations needed using the formula:

$$N = \frac{z^2 p(1-p)}{e^2}$$

Where z is chosen based on a confidence interval, p is the estimated idle time, e is calculated based on er which is the relative error (usually between 1 to 5 percentage) times ps which corresponds to the least interesting activity. This is further explained by Meynard´s industrial engineering handbook chapter 125 (Zandin, 2001a). The conclusion can be drawn that using this formula is most suitable on for example a production line where idle time can occur or when the goal is to identify how much time is spent on different activities and determine the workload is sufficient enough among the operators.

In our case we are only interested in how long it takes to perform the activity of transporting material from A to B. The task will be broken down into three activities: loading of pallet, transportation and unloading of pallet. It will then be easier to identify where time is either lost or gained compared to the AGV or AMR. A set of measurements based on SE standardized way of working will be completed, where the median is chosen. It will also help us identify if work is carried out in a standardised way, or if there is a lot of deviation in how the forklift operators work.

Number of observations

Determining the appropriate sample size of the time study can be done in multiple ways. Some companies have these properties defined and predetermined depending on what type of process is studies. There are also mathematical methods for calculating the required sample size to meet a certain confidence interval. (Zandin, 2001a) In the study performed in this paper a very small sample size of 10 will be used because the process measured is considered to be very stable. And there is a low expected variance between samples.

3.3 Qualitative data collection and analysis

In this thesis a qualitative study will be performed with the intention of gathering information about other AGV implementation projects that have been performed. This information will be gathered by conducting interviews at other companies that use AGVs or AMRs in their materials handling processes. The qualitative study will be designed by using the 5 steps defined by (Bickman & Rog, 2008) in the book The SAGE Handbook of Applied Social Research Methods. These five steps are general guidelines and can be applied to many qualitative study designs. In this study the second step Conceptual framework will not be used.

3.3.1 Interviews

Semi-structured interviews will be performed with people from both the department responsible for the manual press brakes and the logistics department. Establishing communication with all the involved parties and having an open dialogue will make sure everyone is up to speed with the project and that decisions taken are based on facts. This also involves gathering information from operators, team leaders etc through out the project.

Multiple study visits to relevant companies will be conducted and questions will be prepared in advanced. The interviews will follow a semi-structured type, in order to ensure that the right topics have been covered to help answer the questions formulated in the requirements specification. If more technical questions are to be asked, questions will be sent in advanced and discussed afterwards if possible. For example what are the running costs associated with AGVs, how often maintenance needs to be conducted etc. During the site visits the AGV system will be observed based on multiple factors. How does the AGV work in terms of logistics such as flow and material handling. What benefits it brings to the company. But it is also important to look at the safety aspect, how the AGV affects the daily activities and interacts with the operators. But also how the system is supported by the operators.

1. Goals
This study will be a good way to gather information and helpful knowledge about how an AGV implementation project have been conducted in the past. Gathering information from other companies about their experiences and struggles with their projects will help guide this project stay clear of these roadblocks and make the project work more efficient. The study should help identify key factors which are crucial for the project's success.

2. Research questions
The purpose of doing this study is to gain insight into the different processes that are tied to evaluating the possible implement the use of AGVs to support logistics in a manufacturing setting. Meaning to research different areas such as suppliers, factory layout, future growth, what are the requirements from logistics/production and so on. When all the questions have been identified and answered, it will be possible to make a decision whether an implementation of AGVs or AMRs would be suitable or not.

3. Methods
This study will be conducted using interviews and general conversations with employees involved both in-house at SE but also people outside of the company who can provide valuable knowledge and insight. The interviewees at SE will provide information on the current process and the external interviewees will provide information about the AGV/AMR technology. Questions will be formed before the interviews that are open for conversation and discussion. Follow up questions that occur during the interview will be also be asked which will help widen the scope of the questions and discussion. This will help the study to answer questions which might have been forgotten or its importance not realized due to lack of knowledge in the subject. The interviews will be audio recorded and then transcribed. This will help with documenting the answers and creating a more structured result of the study.

4. Validity
Conclusions have a chance of being biased by the experiences from the interviewees. This will be very hard to avoid because its their answers and their knowledge which are searched for. But the study will be based on multiple interviews from different companies which are not affected by each other. This will help with the analysing the answers. Also the identification of possible answers which might be wrong or biased due to the interviewees experiences.

Interviewees
The logistical department is the one responsible for most of the material handling in the factory and it is therefore appropriate to interview regarding questions about the current materials handling process. Interviews will also be conducted with the department responsible for processing of materials, where the press brakes are included. People outside SE such as AGV/AMR suppliers and companies which already have implemented such solutions will also be interviewed with the intent to acquire knowledge from actors with more experience.

3.4 Triple bottom line model

The Triple Bottom Line (TBL) was coined by (Elkington, 2004) in 1997, and is a framework used for measuring success of organisations and performance of businesses driven by sustainability. The three lines are environmental, economic and social. The three lines are also commonly referred to as the 3Ps, refereed to as people, planet and profit. All are equally as important and the goal is to achieve a balance between the three. (Alhaddi, 2015) The TBL will be used as the structure for the discussion chapter. Where each of part of the TBL will be different sections.

People

The people line refers to a business actively working with creating fair and beneficial practices to the community, labor and human capital. By doing so its possible to give back to the community by providing value. This could for example include promoting a safe working environment and negotiating for fair wages. Working with the people line is not only done from the perspective of being a good member to the society, if social responsibility is disregarded it can have a negative effect on the sustainability and performance of the business. It could also result in increased economic costs for the company. The main purpose of the people line is to focus on the interaction between the organisation and community, while at the same time addressing issues related to the community involvement, relations and wages. (Alhaddi, 2015)

Planet

The environmental or planet line refers to organisations performing practices that do not compromise the environmental resources for future generations. Meaning to work with reducing reducing gas emissions and use energy resources in an efficient manner in order to reduce the ecological footprint. An analysis conducted by (A.T, 2009) showed that working towards protecting the environment will also result in a competitive advantage by gaining a financial advantage through the reduction of operational costs such as water and energy use, while at the same time increasing the revenue by developing innovative green products. (Alhaddi, 2015)

Profit

The economic line also known as the profit line refers to how the economic system is affected by the practice of the business organisation. The economic aspect is viewed as a subsystem of sustainability that allows for the company to survive and further evolve their business in the future. The growth of the company ties to the growth of the economy, and as a result effects the economical line. The focus is on the economic value the organisation brings to the surrounding system, which should be done in a way that supports the future generations. (Alhaddi, 2015)

4
Results

In the results the first three steps of the DMAIC model is presented. Where the *Define* section cover requirements which have been defined early in the project. The *Measure* section covers the data and information gathering and *Analyze* section covers the analysis of the information in the *Measure* section. As previously mentioned the last two steps *Improve* and *Control* are outside the scope of this project.

4.1 The results from define step

This section will cover the technical requirements and functions that was determined to be important for the success of the AGV/AMR project from the perspective of SE. The *Risk analysis* section covers risk and risk mitigation regarding the success of the thesis.

4.1.1 Requirements

The chosen AGV solution needs to be able to handle the variance of different articles that are to be transported between the high storage units and the press brakes. In this case all material transported will be stored in plastic containers, which currently is done by placing them on a pallet. The AGV therefore needs to be able to support the transport of plastic containers. However it would also be preferred if the future solution is not only limited to a smaller AGV only capable of transporting plastic containers, since it would then be possible to use it in another application. It's also important to consider the weight of different articles the AGV needs to transport (Prasad & Chakraborty, 2013).

To understand what the different requirements are in order for an AGV to be able to operate, the internal logistic environment needs to be analysed. Communication with the logistics department is key to ensure no information is left out, a contact person from the logistics department has therefore been chosen as well as the production department. The flow path layout needs to be chosen, and in this case, there are two paths available see 4.4 and 4.5. One passing through an area of pallet racks and material handling, and the other one through a production area. Both needs to be evaluated, or if it's possible to combine the two. Based on frequency of transport, AGVs needed, physical restrictions for example columns and narrows spaces. As well as movement characteristics of other forklifts and human interaction. (Mirhosseyni & Webb, 2009)

4.1.2 Risk analysis

To identify risks associated with the project a risk analysis was carried out which can be viewed in the Appendix A.6. The reason for carrying out a risk analysis is to identify potential risks and trying to mitigate them so they do not occur to ensure the success of the project. In the risk analysis carried out in this thesis the three risks with the three highest risk points were:

- Running out of time to complete project (10 points)
- Not enough competence about AGVs in house (20 points)
- Environment not suitable for AGVs (15 points)

Mitigation methods for these risks were defined such as define a clear scope and time frame to ensure that the project will fit inside the available time. To avoid the lack of competence the mitigation method is to cooperate with outside partners with more competence about the topic. Environment not suitable can be solved by either revise the solution to fit the environment or to change the environment to suit the AGV.

4.1.3 Supplier evaluation

In order to find a future partner to collaborate in this project a list was created, identifying the different suppliers offering AGV and AMR solutions. The size would range from well known established companies down to smaller and more local ones. Each company was contacted in order to get as much information about their assortment as possible, since the quality and information available on their websites varied. In order to find which supplier would be the most suitable, they were evaluated based on four different main criteria. Function, load, safety and their availability in terms of support.

The first criteria would include functions that Skandia finds necessary for this project. For example that the supplier can offer a fleet management system in order for SE to grow and implement more autonomous vehicles in more areas of the factory in the future. Another important function Skandia is interested in is for the vehicle to be able scan and learn from the environment as it travels. The process could also be speed-up by loading a 3D-layout of the factory into the software of the vehicles. Otherwise the vehicle may need to rely on reflectors or other equipment in order to navigate. Other important factors are the battery-life, charging time, traveling speed and ability to customise the vehicles.

The type of load is about the support of EU-pallets, plastic containers, maximum load and dimensions. Safety includes the ability to mount a blue spot, bumpers, sound or any other type of warning that helps increase the safety. But also how the laser scanner operates, if it covers both low and high objects etc. The last one is support available and where the company is located. A future partner should preferably be located close in order to establish a good relationship and help reduce the environmental impact. Helping to speed up the implementation phase and when working with daily problems such as quality issues, downtime etc.

In the Appendix A.5 the different suppliers will be rated based on the criteria stated above. A more detailed version have been developed together with the company, but for confidentiality reasons the different manufacturers are only referred to as suppliers and the number of criteria have been reduced in order to be applicable to every supplier.

Supplier 1: The first supplier was the only one that fulfilled all of the criteria, therefore receiving a total of 13 points. The supplier offered AMR of various sizes capable of handling both EU-pallets and plastic containers with the ability to customise. The vehicles operate by using natural environment navigation, and a fleet management system is available if implemented on a larger scale. The company is established in Sweden and can offer close support. In terms of safety the vehicles are also equipped with a bumper that in addition to the lasers can detect and absorb a potential collision. It was therefore decided to continue collaborating with this company.

Supplier 2: The second supplier fulfilled all the criteria expect for natural environment navigation and bumper, receiving a total of 11 points. The different vehicles are capable of handling both EU-pallets and plastic containers. There is also support available close. But since SE is interested in finding a solution that utilizes natural environment navigation, therefore this supplier unfortunately is not an option.

Supplier 3: The third supplier also received a total of 11 points. Although ticking many of the boxes including natural environment navigation, safety and support they only offered vehicles capable of handling bigger loads on EU-pallets. In our case we are interested looking for a supplier that can offer both handling of plastic containers in the case of the press brakes, but also capable of handling EU-pallets when Skandia expands in the future.

Supplier 4: The fourth supplier did only work with AGV and did not offer any natural environment navigation or AMR solutions. There was also no vehicles capable of handling plastic containers. Since this does not fulfill the criteria of Skandia it was not an option.

Supplier 5: The same applies for the fifth supplier who did not offer natural environment navigation or AMR solutions. This company were therefore also not considered further.

Supplier 6: The sixth suppler reached a total score of 11 points and the company offered natural environment navigation and AMRs, but no smaller vehicles capable of handling plastic containers.

Supplier 7: The seventh supplier did not offer any natural environment navigation or AMRs and was therefore ruled out.

Supplier 8: The last supplier received a total of 11 points, offering natural environment navigation and AMR, with support for both EU-pallets and smaller plastic containers. The only downside is that the company does not have any offices located in Sweden, they do however have other sub-suppliers offering their products. It was therefore decided that Skandia wants to continue evaluate the possible of collaborating with the company, depending on the level of support and availability the sub-suppliers can offer.

4.2 The results from measure step

Here all the data collected during the project is gathered. First starting off with quantitative data which have been accessed by utilizing the ERP system MONITOR G5at SE. Followed by a stopwatch study which was conducted in the production. Lastly qualitative data is presented in forms of interviews that was conducted at SE with two managers, the potential future supplier and study visits to other companies.

4.2.1 Data collection from MONITOR G5

In order to identify which article numbers that are produced and then stored in the high storage units, all orders and article numbers stored at warehouse position HISS was extracted from the ERP system for 2022. The raw data was then imported to Microsoft Excel which is used as an analysing tool where different data can be merged and matched sorting by the article numbers.

By filtering on all the articles in the high storage units from previous year and matching it with all articles that have been processed in the press brakes with the same article-number. Most article numbers received back by the system are shown more than once because there have been multiple production orders of that same article numbers. Only the amount of individual article numbers are of interest so by applying an advanced filter in Excel these duplicates can be removed. Approximately 812 articles were identified. The number of articles can change yearly, but the four high storage units currently have an utilization rate of 85%, where 812 out of the total number of articles stored in the HISS warehouse position are delivered from the manual press brakes. The data was exported from MONITOR G5to excel for easier sorting and matching between article numbers and container type etc. This can be seen appendix A.1 A.2 A.3

For every article number it is possible to see in the ERP system what type of packaging is to be used. As they are of different sizes and therefore in most cases require different plastic containers, which then are to be stored in the high storage units. A maximum number of pieces that are allowed to be placed in each container is calculated based on the weight of each containers not exceeding 12 kg.

By analysing the data in Excel based on how many finished orders are reported from the press brakes each year and how big each batch is, and by looking at the number of containers needed for each batch and number of corresponding pallets, it is possible to calculate how many trips are required. This showed that the maximum number of transports occurred in October at a total of 189, with a maximum of 19 per day. The month that usually sees the most orders is May. But due to a scheduled price change that was done last year many customers ordered products before this price increase which resulted in unusually many orders in October. The day that had the most production orders finished in the press brake department was the 16 of May, which had 20 orders finished. And if looking at data from previous years May is the busiest month on the year. See A.4

Today the material handling from the manual press brake machines to T11 is done mostly by the operators themselves. Sometimes they get help from a forklift operator from the logistics department. A forklift operator in the logistics department then clears the T11 storage track and moves it to the right location in the warehouse. For an example the high storage units which would be the HISS warehouse location.

Production groups involved are 1150, 1151, 1152, 1153 (4 press brake machines). Today there are 6 operators running the four manual press brake machines over three shifts. Three operators on the first shift. Two operators on the second shift and on the night shift there is one operator. This means that the four machines are running at 50% capacity. This will be taken in consideration when analysing the data because if an AGV solution is suggested it should be able to handle the max capacity load.

4.2.2 Stopwatch studies results

In MONITOR G5its not possible to extract data which illustrate the exact time duration of the materials handling process from the manual press brake machines to warehouse position T11, neither from T11 to HISS-IN. It's possible to see when the press brake and forklift operators have stamped in and out of work tasks, but the data is not accurate enough to estimate the total amount of time the processes takes.

As described in Section 3.2.3 methodology it was therefore decided to perform a stopwatch study to measure the time it takes for a forklift operator to load a finished pallet from the press brake, transport it to T11 and unload it. Since there are currently four press brakes the distance to T11 will vary, but by performing the study on the press brake located in the middle where three are placed in a line it will serve as a median value. The time from unloading at T11, transport to HISS-IN and unload will also be measured. The data will be used to compare the time between transport of material between a forklift and an AGV. The time required for transporting a pallet from the press brakes to T11 is about 54 seconds, and from T11 to HISS-IN around 46 seconds totaling in on 100 seconds of transport time. These times was created by taking out a mean value of 10 measurements from the two transport steps. So 20 measurements was taken totally.

4.2.3 Interviews results

This section will cover all the results and findings from both the different interviews conducted but also the study visit to a company which uses AMRs.

The results from the interview with Logistic manager

In this section will the answers from the interview with the Logistical manager be summarized. The questions which guided the interview can be seen in the Appendix A.3.

During the interview with the logistical manager the first area discussed was in terms of human resources available in the logistics department. There are currently 12 forklift operators employed full time, working with different transportation's of material throughout the factory. Since the workload is influenced by seasonal demand, the operators are not fully utilized at all time. During low-season it is however possible to re-allocate some of the resources to other departments. During high season four people are working an early shift which is from 05.00-14.00, and four people from 14.00-23.00. On top of that 4 more people are working a regular working day. Out of these 12 operators four are working towards the production department, where material handling to and from the manual press brakes are included.

In total there are 24 different forklifts throughout the factory, meaning other departments that are not a part of the logistical group dedicated to material handling, also have access to forklifts. Its not possible to utilize the JIT-principle (Liker, 2009), for removal of finished goods at the press brake machines because there is no signaling system in place which would notify the logistics department of material that needs to be moved.

One current problem is that there is no way of alerting the forklift operators when finished material from the press brakes is ready to be transported over to T11. As seen in for example Figure 4.2 there is currently a smaller buffer available at most press brakes. But the only way a forklift operator can tell if there is finished material available is by manually circulate the area. As a result press brake operators sometimes move the material themselves, if a truck is available in the department. This work task is however assigned to the forklift operators. SE is interested in setting up a system that alerts the forklift operators when finished material available at the press brakes. But currently MONITOR G5does not have a function that supports this.

In terms of rules for truck traffic the company have created internal truck rules. Right rule applies in all intersections, forks are to be placed backwards in the travel direction with a blue spot in front, maximum speed limit of 7km/h etc. It has been considered to implement one-way traffic in certain parts of the factory in order to increase the safety, but its not implemented yet. The logistical manager also mentioned that they would interested in mapping the logistics flow in the factory, to identify which areas are the most trafficked

One big future challenge in terms of implementing AGVs is that material don't have a designated location in the factory. Its not possible for the forklift operators look in MONITOR G5for a specific location where an items is to be stored or stored. Instead the company have come up with their own system where different pallet racks contain different types of products. Its therefore allowed to place a certain type of material anywhere in the allocated pallet rack. In order to find its place forklifts operators look in MONITOR G5where material previously have been stored, they also have a document attached to each forklift. But as mentioned no designated location in the ERP-system, so its up to the operator to find an available space in the pallet-rack. Other challenges discussed were how an AGV will function together with the current high traffic flow and through narrow spaces. Overall the logistical manager was positive to the possibility of implementing AGVs to help increase automation and help the company grow.

The results from the interview with Production manager

In this section will the answers from the interview with the Production manager be summarized. The questions which guided the interview can be seen in the Appendix A.3.

The present state of production was discussed. It was mentioned that finished goods from the manual press brakes get packaged in different containers. Some are packed in plastic containers of various size and some directly in EU-pallets with collar. There are also parts over 2m in length which also gets stored on EU-pallets but then horizontally. Most products have packaging descriptions connected to them in MONITOR G5but not all products. Many products get packed directly in the right containers at the manual press brake machines but there are also a number of articles which gets packed in EU-pallets, which then later gets repacked before they get stored in the HISS.

In total there are 22 people working in the production department. Seven of them are working in the press brakes on a three shift. With four people in the morning, two people in the afternoon and one person during the night. The operator working during the night is also responsible for keeping the production running in the punch presses, robot cells and other machines included in the production department.

The manager also talked about the future state of SE due to their development of a new company strategy which will grow the company significantly in production volume. This will require more capacity from the production which would according to the manager require one additional press brake machine. The now five manual press brake machines would then be run with two shifts and five persons in each.

The managers view on AGVs or AMRs and what they potentially would mean for SE was discussed. The general view was positive and there was an belief that there could be benefits. But there was also concerns regarding how this would influence the working stations today. The manager emphasized on the large variation in products and how they get packed. And trying to fit a solution that only can handle boxes would potentially be problematic if the work station has to be largely reconfigured to accommodate the AGV or AMR solution.

The manager also expressed concerns regarding how a AGV solution might influence the economical situation for the operators. Right now there are height adjustable work tables at each station to help the operators avoid dangerous lifts and movements.

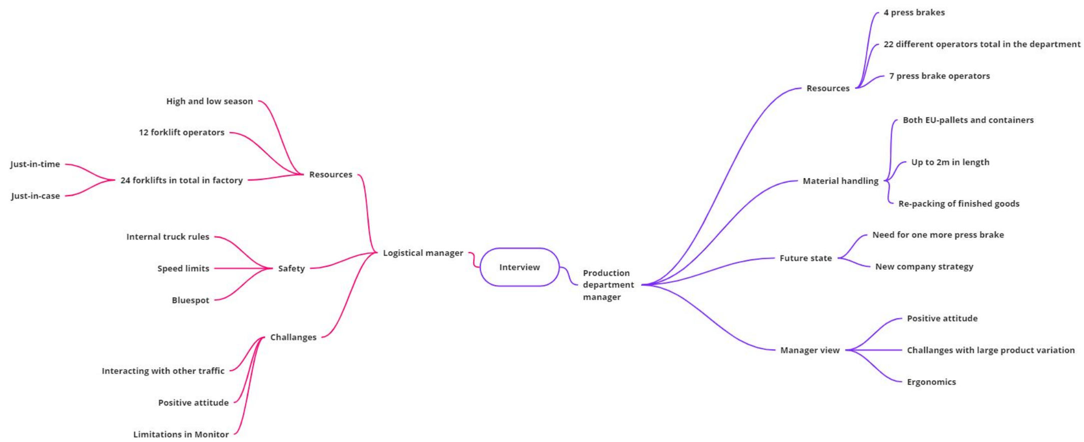


Figure 4.1: Mind map summarizing interviews

The results from the interview with supplier 1

In this section the answers from the interview with supplier 1 will be summarized. The first question discussed was the pick-up and delivery of the plastic containers. For pick-up of material at the manual press brakes a potential solution discussed was to install an additional conveyor band with a smaller buffer at each workstation only dedicated to the AMR and plastic containers. The only problem was the possible lack of space as an operator needs to be able to move freely when picking, processing and depositing material. However this could be solved as the implementation of a conveyor band specifically designed for plastic containers, could mean that the current buffer for EU-pallets available at the station could be reduced, thereby freeing up more space.

It was decided that there needs to be a buffer available when dropping off material at the high storage units. The reason is because there is not always an operator available to load the containers into the high storage units. The availability of the operator depends on the season. During high-season the task of loading and unloading the storage units is a full time job performed by a dedicated operator. However during low-season the operator responsible for the storage units also carries out other tasks. The buffer is therefore needed as an operator is not available all the time, but also in order to the AMR to be able to function during the night.

In order for the pick-up and drop-of of material to work there needs to be a signal system in place communicating with the AMR. It was discussed together with the supplier that a good first approach would be to create a solution that can operate independently of the ERP system. For example using sensors connected to the conveyor band altering the AMR. The reason being its a much simpler solution that would help make the project less extensive, but it would still create the same results. Allowing for SE to make an investment without investing an extensive amount of resources. Especially considering that there are no fixed storage locations for all products and material in the ERP-system. By starting on a smaller scale its possible to gradually learn from the implementation. If there is to be a future implementation of AMRs on a larger scale, SE will already be aware of the many potential roadblocks and pitfalls associated with the process. Another aspect is in terms of cyber security. Connecting the AMR to the ERP system means the AMR needs to be secure in order to not pose a threat of potentially exposing the data of the ERP system. By only relying on sensors the AMR does not have to handle sensitive information or be connected to a WiFi.

The supplier mentioned during this interview will only be responsible for selling the AMR. The configuration of conveyors and the final solution presented will be performed by another company acting as a system integrator with a license to sell their products. Meaning that future support unless directly related to the AMR itself will not be handled by supplier 1. Such as implementation a long with training and educating operators at SE on how to operate the AMR. They will also be responsible for future support. Maintenance costs of the AMR were also discussed, but this is heavily dependent on the usage and how well it is maintained.

No additional infrastructure would be needed in order for the AMR to navigate. There are clear reference points available for example in the pallet racks that can be used. In certain areas on the production floor where material such as pallets is stored and therefore may not be present at all time, its possible to set up smaller guard rails as reference points. This is done in order to prevent the AMR from having to spend an unnecessary amount of time repeatedly scanning the environment for objects and adapting its route. It may therefore be more beneficial to treat the zone as a permanent object. The battery range was also discussed. The battery life is dependent on the weight of the load but also how it is charged during the days.

The results from study visit

The first topic discussed was how an AMR is used within the company. Today one AMR is utilized and the work tasks consists of transporting goods stored in EU-pallets between different locations. The fleet management is not connected to their ERP-system, instead signals are communicated through manual buttons available at each pick-up and delivery station. There are multiple delivery stations available in the factory, and each delivery station have a set of different buttons connected to each station. The operator therefore have to know which station different products belong to, in order to send material to the correct location. Since the AMR is not connected to the ERP-systems, human errors are easier to correct as mistakes such as sending material to the wrong location simply be reverted by a manual forklift.

The investment was mainly done to save in on forklift operator time and also improving the safety by reducing regular forklift traffic. One key point that was brought forward was that they tried to keep it as simple as possible. Hence the use of physical buttons for creating job orders for the robot and not the integration of the ERP-system.

One large benefit according to Company A was that the AMR system was easy to implement and also to make changes. The whole installation process took according to them around eight hours. And making changes such as moving and adding tasks and picking stations also takes little effort. Adding picking stations was also relatively cheap compared to the initial investment cost of the robot plus charger. The robot itself was the most expensive investment.

The daily operations of the robot was smooth and there were little to no problems with the performance of the robot. The only ongoing maintenance was that the sensors needed to be cleaned from dust once per week. Even thought the robot was equipped with lamps and speakers which emit warning sounds some accidents happened where forklift operators drove into the robot. The company warned about the robot operating in direct sunlight which could potentially disrupt its cameras. This was something their AMR supplier had warned them of but nothing they had experienced yet.

4.3 The results from analyze step

This section will cover the analysing and combination of information from the earlier sections in the Result Chapter. Starting of with a *Material flow* that dissects how material move in the production today. *Material flow simulation* presents the results and outcomes from the simulation created in Visual Components. The *Return on investment* section combines data from both the Stopwatch study and MONITOR G5to estimate the cost savings with the AGV/AMR implementation. *Supplier evaluation* covers the analysis of the best fit supplier which will be recommended to collaborate with for SE.

4.3.1 Present state analysis

The Present state analysis presents important aspects of the material handling process today. Starting with how the *Material flow* is through the factory. The warehouse location and storage units are presented in the section *High material storage*. Packaging and pallets presents what type of containers currently used. *Logistics handling technologies* presents the equipment used such as forklifts. The safety section analyses the safety aspect of the material handling process today.

Material flow

The material flow that will be investigated in this project is the flow from the 4 manual press brake machines out to the four high material storage units situated in another area of the factory. Today finished goods from the manual press brakes are delivered in two separate ways to the storage units.

Figure 4.2: Press brake 1151

The most commonly used path is the green one (see 4.4), where material first is delivered to a conveyor band acting as a buffer. Multiple pallets not only arriving from the press brakes are stored here, meaning that the transportation time from press brake to high storage are not consistent. As it is dependent on two factors. How many pallets are in queue at the conveyor band, and when a truck operator is available to empty the band. The press brake operators enter the conveyor band (T11) as warehouse location input in the ERP-system, and forklift operator changes it from T11 to the storage units (HISS).

Figure 4.3: T11 Load Position

The second path is the yellow (see4.4), where finished goods from the press brakes are delivered directly to the storage units. The main difference between the two material transportation's except for the buffer, it's the number of involved forklift operators. When directly transporting the goods, only one operator is involved. But with the buffer, an additional operator is involved. One that delivers material to the buffer, and a second one emptying the buffer.

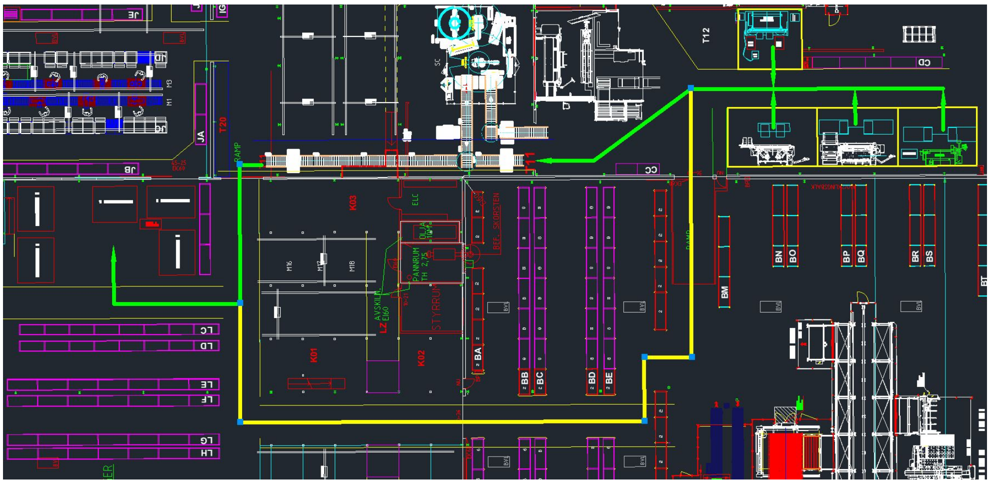


Figure 4.4: Material Flow Path

An alternate material flow path which can be seen as the red thick line in 4.5. This route is very rarely used today when transporting material from the manual press brakes. This route is less trafficked than the yellow path in 4.4. The red path will be considered an option for the AGVs to use.

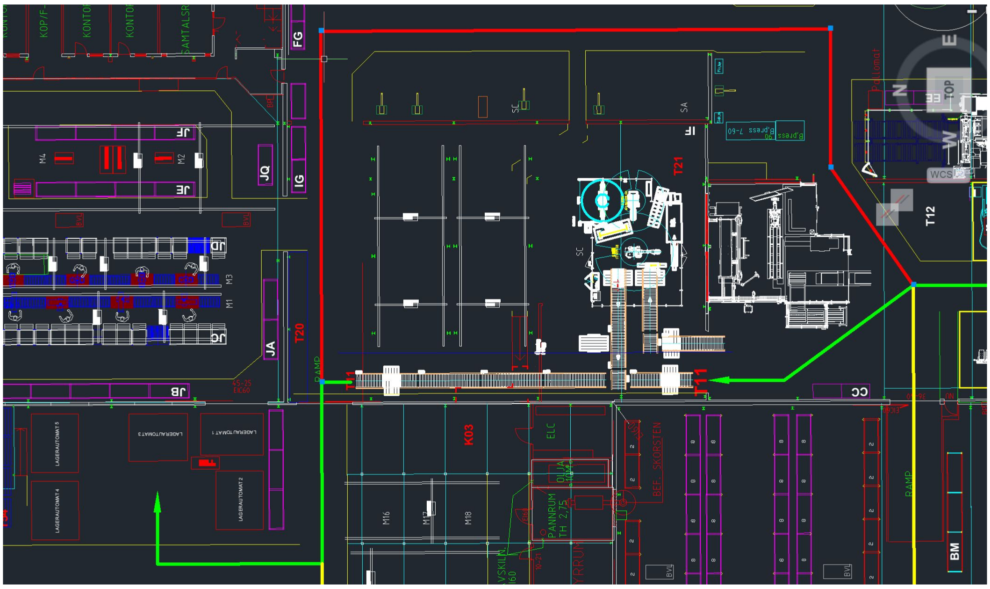


Figure 4.5: Alternate route

High material storage units

There are 4 high material storage units which are run by a computer connected to MONITOR G5. Orders can be put in the computer and the storage units will automatically pull out the right storage level and present it to the operator. The storage units are of the model Compact Twin from Weland Solutions (Weland solutions, 2023). The storage units right now need to be loaded and unloaded by an operator. The process consists of a forklift operator moving the material from T11 to a designated storage area called HISS IN, in front of the high storage units. The material is then moved manually by hand from HISS IN into the the storage unit HISS. After this, an operator enters the article number and quantity into the storage unit and the computer decides on which shelf it will be stored. The shelf is brought down by the machine and the material is entered. A material location change is also performed in the ERP-system from location HISS IN to HISS

Packaging and pallets

Today finished goods are either placed in plastic containers of various sizes, or directly into an EU-pallet with a collar. Each different article and their corresponding containers have a maximum number of products that are allowed to be stored. Which is calculated based on a certain weight. This is also important from an ergonomic perspective, as the operators manually have to lift the containers while loading and unloading the pallet. The number of possible containers to be placed on a single pallet varies, since the plastic containers differ in size. Meaning that for

certain batches only one transport may be necessary from the press brakes to the high storage units, while others may require more trips. Even if SE is interested in a solution where the plastic containers are transported without a pallet, it could still be of interest to see how many containers fit on a pallet for a future reference comparing with an AGV solution. The most commonly used containers and how many can be placed on a single EU-pallet is presented below:
EU-pallet size: 1200x800mm
Container 1: 600x400x200, possible to store 2 on a EU-pallet. See Figure A.1
Container 2: 600x200x150, possible to store 5 on a EU-pallet. See Figure A.2
Container 3: 400x300x200, possible to store 6 on a EU-pallet. See Figure A.3
Container 4: 300x200x150, possible to store 11 on a EU-pallet. See Figure A.4

Logistics handling technologies

Today most of the materials handling is preformed using different types of forklifts operated by personnel. There is both regular forklifts but also counterweight forklifts. There are also smaller forklifts operated by hand for moving things on floor level. There are also larger forklifts present in the factory but these are never moving in the areas considered in this project. In the manual press brake department, there is always one forklift parked being ready to use by the personnel. This forklift is parked here so the operators of the press brake machines can move finished products to T11 by their own. Not needing to call in additional logistics personnel for this task. But also since there is no current system in place altering the logistics department of when to move finished material from the press brakes to T11.

Safety

The material handling processes which move material around in the factory is today handled fully by operators and with the help of various forklifts. The electric drive forklifts are equipped with audio signals and also blue spot lights which help notifying nearby operators of the forklifts presence. There are no current sensors or detection systems in place in the forklifts that could potentially help hinder an collision. The safety of operations is completely dependant on the actions of the forklift operator. Much of the material handling processes are therefore under the influence of the human factor.

Pallet racks are equipped with physical safety barriers which reduce the severity of an impact to the pallet rack. These bumpers or shields do not help reduce the likelihood of an collision but rather reduce the damage done to the pallet racks. They do not help reduce the damage done to the forklifts however. There are also zones which forbid truck traffic due to the roof being to low. Warning signs are used for these zones.

4.3.2 Material flow simulation

The model was built with the 2D factory layout as the floor. This meant that the placement of resources and other objects have the right dimensions and correspond with reality. All objects such as pallet-racking, conveyor bands, different types of AGVs sorted by manufacturers etc was available in Visual Components. The only resource not available was the press brake, it therefore had to be imported as a STP-file and modified within the program in order to work. After the model was completed and all the components have been integrated it was time to start building the simulation.

In order to connect different resources a flow is created between the machines. The flow directs how parts are transported within the system. In our case an assembly was first created consisting of a Euro-pallet with collar, with attached parts. Here its possible to adjust the interval of how often a pallet is created, and how much many components are to be attached. The pallet is the distributed to the four different press brakes by a manual forklift. The priority is set so material is delivered to the first available press-brake, whenever a pallet is ready. The parts are then processed by the press brake and its corresponding operator, and finished parts are placed into a new pallet. Here its also possible to adjust parameters such as process time, downtime, and time-to-failure. Whenever a pallet is ready for pick-up the AGV will pick the pallet and deliver it to the area where the high-storage units are placed. The priority of the AMR is set to first available. In figure 4.6 one of the four press brake stations built in Visual components is shown a long with an AMR.

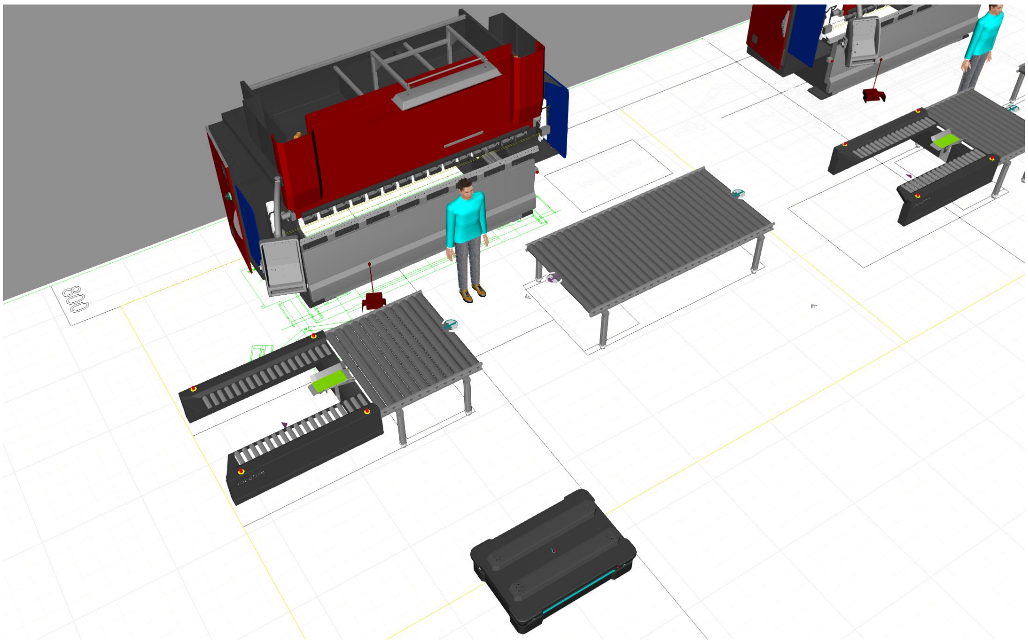


Figure 4.6: Pressbrake & AMR

With the created simulation it is possible to measure the travel time for which it takes the AMR to move material from a press brake machine to the HISS warehouse position on the yellow route in Figure 4.4. The AMR was set to have a travel speed with payload of 1200 mm/s which is the speed Supplier 1 AMRs operate. The material delivery time was measured to 1 minute and 52 seconds. The AMR was not interrupted by any other resources during this test simulation which makes this time a best case scenario for the AMR. In figure 4.7 the AMR can be seen carrying cylinder goods representing finished products traveling through the warehouse.

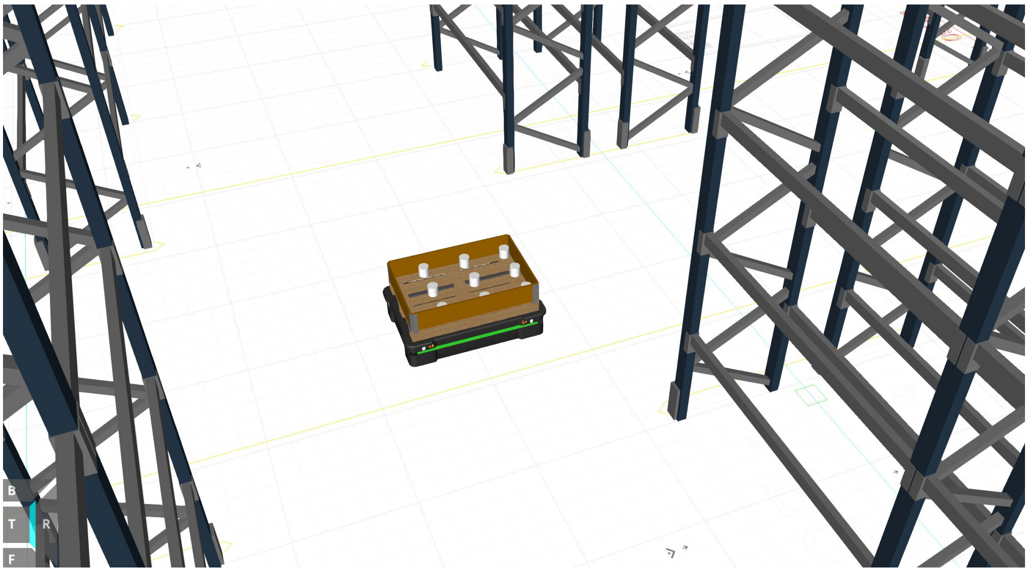


Figure 4.7: AMR traveling through the warehouse

4.3.3 Return on investment calculations

The *Return of investment* of the AGV will be simply calculated by estimating the current amount of resources used to handle the material moving process from the Press brake department to warehouse position HISS. This can be done by combining the MONITOR G5data from Section 4.2.1 and the Stopwatch studies from Section 4.2.2. Combining the amount of production orders finished and the amount of time it takes for a operator to move this material and finally multiplying this with the cost per hour for an operator with a forklift the resources consumed can be estimated.

The current material moving time was measured in Section 4.2.2 and combining both the time from press brakes to T11 and T11 to HISS the time was 96 seconds. Data from Section 4.2.1 showed that 1603 orders where finished and later moved to HISS warehouse position for 2022. Assuming one finished order at least equals to one EU-pallet being moved the time spent for this task per year equals to 44.5 hours. Multiplying this with the cost of 386 SEK per hour results in the cost of roughly 17 000 SEK per year spent on this specific material moving process.

4.3.4 Choosing route

As previously mentioned there are two current routes the AGV could travel from the manual press brakes to the high storage unit. One is through areas of pallet racks where the main tasks are to perform material handling, while the other one is through a production area. It was decided by Skandia that the first option through the pallet racks would be the most suitable. The decision was based on factors such as the level of human and forklift interaction, moving goods, the quality of the flooring, narrow spaces and width of aisles etc.

The most limiting factor and the reason for not choosing the second path is the level of human interaction. The main reason why Skandia wants to implement AGVs is to reduce the number of accidents related to forklift traffic. Here people are continuously moving through the aisles, meaning that if an accident is to occur the risk of an employee getting injured is higher compared to the first path where it most likely only would occur in damage to the goods, since material handling is carried out mainly by forklifts. The main activities in the second path are moving material with a hand forklifts and stamping jobs on a nearby computer. Hand forklifts are used in combination with forklifts due to the narrow spaces in the welding and painting areas located close by.

Pallet racks are also placed a long the way, meaning forklifts sometimes operate directly in the aisle. Compared to the first route where no material handling is carried out directly in the path the AGV would travel, since the pallet racks are located in separate aisles along the main path. The flooring and surface quality is also much smoother through a larger portion of the route in the first path. This is because it travels through a hall which was newly built. Another argument is that offices, a dining hall, and toilets are located closely to the second path meaning there is a lot of activity through the aisles by people not regularly working there.

5
Discussion

The discussion chapter will be divided into four parts. The first three being connected to the Triple Bottom Line model which is Profit, People and Planet. The findings in this thesis will be divided up between these different sections. The final verdict on feasibility chapter will present the final recommendation for the company and chapter will be ended with the section Theoretical contribution where the thesis contribution to the scientific topic of AGV/AMRs.

5.1 Profit

This section will cover the content which are of economical and numerical nature. First explaining the economic impact of the AMR investment and secondly the thoughts and conclusions from the simulation.

Economic impact

The direct economic gains from an AMR implementation on the material handling process covered in this project is very small. When the potential cost savings was done in Section 4.3.3 the estimated savings would be around 17 000 SEK per year. Comparing this to an investment cost that could range anywhere from 500 000 SEK up to 1 000 000 SEK, depending on model and accessories the ROI will be very long. In the case of 500 000 SEK the ROI would be approximately 29 years.

The desired ROI is between 1-10 years at Skandia. Based on this the potential economic gains today will not be the motivating factors for going further with an AMR implementation. But if the AMR is set to perform more tasks which would increase its use an AMR solution might be relevant in the future when the capacity demands are increasing. The time saved for the process covered in this thesis is to low to make the investment realistic on an economic level. If backtracking from the estimated 500 000 SEK investment cost with the hourly operator cost of 386 SEK and dividing that with 10 years write of time it would result in around 130 hours.

It must be mentioned that the time saved with an AMR solution is only based on a very optimum situation. There is no consideration of the time it takes for an forklift operator to travel to the process. There is also no consideration for forklift operators being distracted with other tasks or people when performing the task which could affect the transport time considerably. So the calculated time saved is most probably in the lower end of the spectrum and could be higher in reality.

Outside of the direct economic gains there are indirect one which could help justify an investment in AMRs. One example is the reduction in damages to both equipment and goods transported in the factory due to the increase in safety with the use of AMRs compared to regular forklift traffic. These cost reductions are however hard to estimate because they vary much in nature and also in frequency.

Starting to pack products in the desired container directly at the press brake machines would also lead to a cost saving, because this would remove the extra work that happens when products gets repacked at the HISS warehouse position and the EU-pallet packing needs to be handled. This however does not have a direct connection to the AGV/AMR project and should be conceived as its own cost saving and not be included in this thesis.

Simulation

The simulation created using Visual Components has mostly been used for visualisation and less of calculation than what was planned from the beginning. The need for simulating and gathering data about the AMR traffic was not as high as first thought. As the data finally showed the utilization level was low on the AMR there were no need to simulate the need of multiple mobile robots. The software was however used to estimate the travel time for the AMR from the press brake department to the high storage units, which resulted in a travel time of 112 seconds. This time is the best case scenario where no interference with other traffic or humans is taking place. (Section 4.3.2)

5.2 People

The people section will cover how the AMR investment would affect the people at SE. Mainly the production/logistics employees. First discussing the safety aspect of the technology. The competence and knowledge building aspects of the investment and finally the social impact of the investment.

Safety

As previously mentioned, today the highest number of accidents occur within the logistics department. Safety has since the beginning of this project been the main reason for why SE wants to evaluate the feasibility of implementing autonomous vehicles. These accidents are related to loading and unloading material into pallet racks, damage to infrastructure and in worst case causing harm to people operating the forklifts or people walking nearby. The common denominator of why accidents occur is the human factor.

In Section 2.3 the different characteristics of AGV/AMRs are described. This helps to give a good understanding of similarities and what separates an AGV/AMR compared to a manual forklift. In terms of pathing the main concern is how well the current layout supports autonomous vehicles. As previously mentioned the chosen route partly consist of a newly built area where the surface is smooth and the aisles are wide enough allowing for vehicles to pass each other. The same goes for the second part of the factory the vehicle travels through. The AGV/AMR should have no trouble transporting material based on the current layout.

It would have been interesting to create a flowchart in order to visualize the current traffic, and predict where the most likely causes of interaction or stops would occur. But this would have been to extensive considering the large number of forklifts operating the factory on a daily basis. Instead its possible to utilise safety features such as limiting the speed of the vehicle when entering a specific zone. In terms of guidance SE is interested in a solution utilising natural environment navigation. Meaning the vehicle will be able to operate without the need of additional equipment such as reflectors. In terms of safety this allows for more flexibility since the vehicle can calculate a new route and navigate around objects. Instead of becoming stationary while waiting for the object to be removed.

If choosing a solution where the vehicle is sufficient enough to utilize a single battery between the charges, the safety is also increased as the vehicle is capable of charging the battery without any human interaction. Compared to a normal forklift that often uses lead batteries containing sulfuric acid which causes risks associated with the charging such as, releasing explosive gas therefore requiring a ventilated and safe area where the chances of sparks occurring are low in order to charge safely. But also additional protective equipment and the correct training.

As previously mentioned one safety aspect is the loading and unloading of pallet racks. Although an AGV/AMR wont operate at any height except for ground level, the precision will always be accurate. Meaning there will be no accidents or damage related material being misplaced. It will also help create a safer working environment around the press brakes as it reduces the number of forklifts operating in the area. AGV/AMR robots compared to regular forklifts have the function of traceability as standard. Meaning that all the actions performed and distances driven can be logged. Also the current position of the vehicle can be seen. The ability to trace traffic can be used to map the traffic in a facility and help with decision making and layout and route changes for traffic. This is a function which does not exist today and something that the Logistics manager in Section 4.2.3 said would be a helpful function. The tractability aspect was also something that was brought up by Supplier 1 in Section 4.2.3.

Investment in competence

As said in Section 5.1 the financial gains will not be the motivating factor to proceed with the implementation of an AGV in the the area covered by this thesis. However there are areas of value which can not be measured such as investment in knowledge and competence. Currently there exist no knowledge or experience about AGV/AMRs at SE. Therefore it is not straightforward for the company where in the material flow this technology would benefit them the most. Starting off with a small pilot project with the intent to learn and get comfortable with the technology will allow them to more efficiently use the digital technology.

Impact on workforce

Investing in automation can be very success full many times but can also be the cause of conflict with the working force at an company. Automating processes and changing out humans for machines will naturally create a resistance for change because it can be seen as a threat to the workers jobs. But automating processes does not always mean that a reduction in the workforce is coming. As described in Section 1.4 SE have the ambition to grow their sales and production quite much the next coming years and this will mean that there will be need for more capacity in the production and materials handling. So the investment in automation could mean that instead of having to increase the amount of forklift operators they can instead make better use of the employees they already got. Automating very basic tasks such as moving material from A to B would free up operator time which then can be used at more complex processes where automation is not an option.

Investing in an AGV/AMR will also require some employees to be responsible and maintaining the system so it is operating as intended. Meaning that the operators will get the possibility to increase their competence and learn new things. This will mean more variety in their work tasks which will make the job more fun and engaging.

5.3 Planet

The sustainability from the planet perspective is important, and deals with how companies are working with sustainability in order to reduce the impact on the planet. By utilizing an AMR instead of a forklift its possible to reduce the energy consumption. A forklift is heavier and includes the weight of an operator. For smaller transports of for example plastic containers that do not require the lifting power of a forklift, an AMR will be more suitable and result in a more efficient energy consumption. Since the human factor is ruled out and the navigation relies on sensors, there will be no repair costs associated to damage that can occur because of the human factor. Such in the case of a forklift, where its not uncommon that accidents occur where operator drive into objects or damage goods. Unless the AMR is damaged in the case of an accident caused by a forklift operator, repair costs associated with the AMR will only consist of wear parts for example wheels.

A part that also degrade over time is the battery, which is highly dependant on how well its maintained through charging. The battery can only perform a certain amount of charging cycles from when its new. Too short and frequent intervals between charge cycles will reduce the battery life, and in order to keep it healthy and long lasting its important to oversee the energy consumption and coordinate charging accordingly, allowing for the battery to reach a full state. If the capacity of one AMR is enough but the battery is not sufficient enough to cover the different shifts, a more sustainable solution could be to buy an extra separate battery instead of having to invest in a second AMR.

Other aspects that can increase the sustainability aspect is to chose a supplier available locally instead of an internationally. Reducing the number of transports and thereby emissions, but also decreasing the shipping and storage costs. But also to collaborate with a manufacturers that works with making their products recyclable, and that are aware of their supply chain and how their suppliers are working to promote sustainability. Investing in digital technology such as an AMR also helps increase the profitability and efficiency in the factory, thereby utilizing resources better and making them more efficient. It also helps improve the quality of products, which in return can make them longer lasting and as a result have a lower impact on the environment.

5.4 Final verdict on feasibility

This section will be answering the thesis research questions one by one.

RQ 1 - What impact would this implementation have on the economics, safety, efficiency, sustainability of the process?

From an economical perspective the short answer is that the ROI for implementing an autonomous mobile vehicles most likely will be too long in order to meet desired ROI set by SE. The reason for the ROI being so long is that there are relatively few of the orders (around 20% of the produced orders) in the manual press brake department which will be stored in the high storage units. Resulting in a too low utilization of the AMR if it only would carry out the task described in this thesis. The recommendation to SE is to expand the list of work tasks which the robot shall perform resulting in a higher utilization and therefore a lower ROI. If the work load of 42 hours per year could be expanded to 130 hours per year a ROI of 10 years can be meet as described in Section 5.1.

The calculations are also based on a best case scenario regarding transport time. There are also other aspects of time such as traveling to and from the work tasks, and waste that occur during the material handling that are hard to estimate and not taken into consideration. In reality the ROI therefore most likely will be a little lower than the estimated 28 years calculated in Section 5.1. If considering the growth plan of SE the amount of hours required for moving material from the manual press brakes to the high storage units will increase. This would also result in a increase in utilization of the AMR.

The main motivation behind starting this project was to increase the safety. Setting a price on safety is therefore hard as it is within every company's interest to reduce the number of accidents as much as possible. This in itself can be enough of an argument to invest in autonomous mobile robots. The more precise movements results in no damage to the infrastructure or goods, and less chance of causing harm to the operator. It also creates a safer working environment for people who encounter or work close to the vehicles. As well as help reduce repetitive work tasks reducing the stress of operators.

From an environmental perspective the use of AMR is a step in the right direction as it it reduces the electricity consumption and repair costs compared to a normal forklift. By investing in digital technology its possible to better utilize resources and become more efficient, reducing waste and the impact on the environment.

RQ 2 - Are there other areas of benefits to SE in terms of investing in AGV/AMRs?

If SE wants to expand their capabilities and gain competence in this area of material handling this pilot project is a good start. It is not to complex and the functionality of the solution is almost guaranteed. When SE has gained competence and knowledge about this type of systems they can later expand it to other areas of material handling in their factory and increase the utilization of the AMR and start gaining real economical benefits.

RQ 3 -Is it feasible to implement an AGV/AMR system in the handling of material from the press brakes to high storage units?

The overall recommendation is that if the economic side of the investment is less relevant and the other benefits such as the increased safety and competence building aspects of the project they should continue with the project. There are little to no changes needed in the environment at SE and the AMR system does not need a integration with the ERP system but can operate as a completely separate system, meaning the installation process will be very easy and short.

5.4.1 Theoretical contributions

The thesis has made theoretical contributions to future research by assessing the feasibility of implementing an AMR as a pilot project in a SME. While numerous studies discuss the topic as summarized in the literature review in theoretical background chapter, many of them emphasize broader-scale implementations often accompanied by the construction of new factories or production lines. However, our study places emphasis on safety as the primary driving force, which is also interconnected with sustainability. By collaborating with the case company, this Master's thesis expands the research field to encompass smaller-scale implementations that aim to enhance workplace safety and efficiency through the utilization of AMRs.

.

6 Conclusion

The purpose of this Master´s thesis is to investigate if it is feasible to implement an AGV/AMR solution at SE from an economical, safety, efficiency and sustainability perspective but also if there are other areas of benefit from such a solution.

The main conclusion is that it is feasible to implement an AMR for material handling from the press brakes to the high storage units in the current factory setting. By utilizing an AMR no changes need to be made to the infrastructure and many of the products produced at the press brakes can be transported in plastic containers which are suitable for an AMR. It does however require some modification to the material tables which are placed in front of the press brakes, preferably two separate flows capable of handling both EU-pallets and plastic containers allowing for both autonomous mobile robots and forklifts to work in cooperation. Another aspect which makes the project feasible for the the company is that the implementation can be started on a smaller scale without having to integrate the ERP-system. This in turn makes the implementation rather simple and this should mean that there are less disturbances during the implementation but also during the operation of the system.

From an economical perspective the calculations show that the ROI will be too long, based on the number of transport that start at the press brakes and end up at the high storage unit. The ROI does however not take into account some of the other factors affecting time such as initiation of transport, waste and future state. The economical perspective is however not the main reason why SE wanted to initiate this project. Reducing the number of accidents, especially in relation to the logistics department and creating a safer working environment is something SE is actively working with and want to further develop. The advanced technology of an AMR reduces the number of accidents related to human error, and allows for better traceability.
The forklift operator which is a valuable resource, can be used for better suited work tasks requiring creative thinking, collaboration, communication. Concluding the impact on the planet in terms of sustainability there will small benefits compared to the current processes. The AMR will most probably use less electricity and there is also fewer parts to maintain compared to a regular forklift. Meaning that the total environmental footprint will be smaller but only marginally.

Investing in an AMR would serve as a pilot project for SE, its therefore important to realise that there are other benefits that will come as a result of the project. One is the increase in competence about autonomous mobile robots, the process of implementation and how to more efficiently use the technology and expand its use further in the materials handling process. To conclude this Master´s thesis our final recommendation is for SE to continue work towards installing and using AMRs to support the material handling. Due to the narrow scope of the project the economic gains was relatively low. This can however be improved by an increased scope and the addition of more work tasks which lead to a higher utilization rate of the AMR.

Bibliography

6 River Systems. (2019). What are automated guided vehicles? https://6river.com/what-are-automated-guided-vehicles/

agvnetwork. (2022a). How does an AGV Safety System Work? https://www.agvnetwork.com/automated-guided-vehicles-safety-systems

agvnetwork. (2022b). Types of AGV Navigation Systems. https://www.agvnetwork.com/types-of-navigation-systems-automated-guided-vehicles#magnetic-spot

agvnetwork. (2023). What are the main AGV Battery Charging Systems? https://www.agvnetwork.com/automated-guided-vehicles-battery-charging-solutions

Ahnell, P., & Rosengren, S. (2021). *Designing an Automated Guided Vehicle configuration software* (tech. rep.). Department of Industrial and Materials Science. Gothenburg. https://odr.chalmers.se/server/api/core/bitstreams/36a4ba92-0da3-4a7a-bc9b-8ae5eb09d29d/content

Alhaddi, H. (2015). Triple Bottom Line and Sustainability: A Literature Review. *Business and Management Studies*, *1*(2), 6. https://doi.org/10.11114/bms.v1i2.752

ANSI. (2019). ANSI/ITSDF B56.5-2019: Guided Industrial Vehicles. https://blog.ansi.org/2019/08/ansi-itsdf-b56-5-2019-industrial-vehicles/#gref

Anu, M. (1997). INTRODUCTION TO MODELING AND SIMULATION. *Winter Simulation Conference*. https://dl.acm.org/doi/pdf/10.1145/268437.268440

Arbetsmiljöverket. (1988). BLYBATTERIER - Arbetarskyddsstyrelsens kungörelse med föreskrifter om blybatterier för drivning av fordon samt allmänna råd om tillämpningen av föreskrifterna.

A.T, K. (2009). "Green" Winners: The Performance of Sustainability-focused Companies During the Financial Crisis. *A.T. Kearney*.

Bickman, L., & Rog, D. (2008). *The SAGE Handbook of Applied Social Research Methods* (Vol. Second Volume). SAGE Publications. https://books.google.se/books?id=m4_MAwAAQBAJ&dq=qualitative+study+&lr=&hl=sv&source=gbs_navlinks_s

Čech, M., Wicher, P., Lenort, R., Malčic, T., David, J., Holman, D., Staš, D., & Záruba, J. (2020). AUTONOMOUS MOBILE ROBOT TECHNOLOGY FOR SUPPLYING ASSEMBLY LINES IN THE AUTOMOTIVE INDUSTRY. *Acta logistica*, *7*(2), 103–109. https://doi.org/10.22306/al.v7i2.164

Correia, N., Teixeira, L., & Ramos, A. L. (2020). Implementing an AGV System to Transport Finished Goods to the Warehouse. *Advances in Science, Technol-*

ogy and Engineering Systems Journal, *5*(2), 241–247. https://doi.org/10.25046/aj050231

Elkington, J. (2004). *Enter the Triple Bottom Line* (1st Edition). Routledge.

Evantal, E. (2022). Why IT Automation Is About People, Not Just Costs.

Fragapane, G., de Koster, R., Sgarbossa, F., & Strandhagen, J. O. (2021). Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda. *European Journal of Operational Research*, *294*(2), 405–426. https://doi.org/10.1016/j.ejor.2021.01.019

Ražík, J., Dekan, M., Beňo, P., & Duchoň, F. (2022). Fleet Management System for an Industry Environment. *Journal of Robotics and Control (JRC)*, *3*(6), 779–789.

Hovair Systems. (2023). Different types of Automated Guided Vehicles and their Usage. https://www.hovair.com/different-types-of-automated-guided-vehicles-and-their-usage/

Hrušecká, D., Lopes, R., & Juřičková, E. (2019). Challenges in the introduction of AGVS in production lines: Case studies in the automotive industry. *Serbian Journal of Management*, *14*(1), 233–247. https://doi.org/10.5937/sjm14-18064

Lars, S., & Folke, H. (2017). *Sex Sigma* (Vol. Second volume). Studentlitteratur.

Le-Anh, T., & De Koster, M. (2006). A review of design and control of automated guided vehicle systems. *European Journal of Operational Research*, *171*(1), 1–23. https://doi.org/10.1016/j.ejor.2005.01.036

Liker, J. K. (2009). *The Toyota way* (1st ed.). Liber.

Loebick, K. (2022). DMAIC – Our Favorite 6 Sigma Word of the Day!

MAX AGV. (20223). AUTOMATED GUIDED VEHICLES. https://maxagv.com/automated-guided-vehicle/

MIR. (2023). AGV vs. AMR - What's the Difference? https://www.mobile-industrial-robots.com/insights/get-started-with-amrs/agv-vs-amr-whats-the-difference/

Mirhosseyni, S. H. L., & Webb, P. (2009). A Hybrid Fuzzy Knowledge-Based Expert System and Genetic Algorithm for efficient selection and assignment of Material Handling Equipment. *Expert Systems with Applications*, *36*(9), 11875–11887. https://doi.org/10.1016/j.eswa.2009.04.014

Monitor ERP. (2023). MONITOR ERP SYSTEM. https://www.monitorerp.com/erp-system/

Prasad, K., & Chakraborty, S. (2013). A quality function deployment-based model for materials selection. *Materials & Design*, *49*, 525–535. https://doi.org/10.1016/j.matdes.2013.01.035

SALMINEN, S., & TALLBERG, T. (1996). Human errors in fatal and serious occupational accidents in Finland. *Ergonomics*, *39*(7), 980–988. https://doi.org/10.1080/00140139608964518

Toyota. (2023). What are Automated Guided Vehicle (AGVs)? https://blog.toyota-forklifts.co.uk/what-are-automated-guided-vehicle-agv-robots

Tralert. (2023). BLUE LIGHT ON FORKLIFT TRUCK, WHAT DOES THIS BLUE LIGHT DO? https://www.tralert.com/en/blog/blue-light-on-truck-what-this-blue-light-does/

Vis, I. F. (2006). Survey of research in the design and control of automated guided vehicle systems. *European Journal of Operational Research*, *170*(3), 677–709. https://doi.org/10.1016/j.ejor.2004.09.020

Visual Components. (2023). Visual Components 3D Manufacturing. https://www.visualcomponents.com

Weland solutions. (2023). Compact Twin. https://www.welandsolutions.com/en/product/compact-twin/

Yan, R., Dunnett, S., & Jackson, L. (2018). Novel methodology for optimising the design, operation and maintenance of a multi-AGV system. *Reliability Engineering & System Safety*, *178*, 130–139. https://doi.org/10.1016/j.ress.2018.06.003

Zandin, K. B. (2001a). WORK SAMPLING AND GROUP TIMING TECHNIQUE. In *Maynard's industrial engineering handbook, fifth edition* (Fifth). McGraw-Hill. https://www.books24x7.com/marc.asp?bookid=15205

Zandin, K. B. (2001b). STOPWATCH TIME STUDY. In *Maynard's industrial engineering handbook, 5th edition* (Fifth). https://www.books24x7.com/marc.asp?bookid=15205

A

Appendix

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

A.1 Container models

Figure A.1: 600x400x200mm in pallet

Figure A.2: 600x200x150mm in pallet

Figure A.3: 400x300x200mm in pallet

Figure A.4: 300x200x150mm in pallet

A.2 Monitor data

	Production group	Machine Name	Type	Ordernumber	Articlenumber	Name	Real finished date	Planned Quantity	Reported Quantity
2	1150	Manuell Kantpress 100T	Manuellt arbete	72298-4	EF3226	Låsbygel Fot SEH63-28	2022-01-20	2,00	2,00
3	1150	Manuell Kantpress 100T	Manuellt arbete	72844-20	EF3226	Låsbygel Fot SEH63-28	2022-01-20	2,00	2,00
4	1150	Manuell Kantpress 100T	Manuellt arbete	P242368	ES1355	Remskarv Vinkel SEI50/18	2022-01-10	90,00	90,00
5	1150	Manuell Kantpress 100T	Manuellt arbete	P242855	EH1477	Backsp. Stopp SEI50/18-23 Sk4282	2022-01-10	33,00	32,00
6	1150	Manuell Kantpress 100T	Manuellt arbete	P243006	GF01015	Fäste Reglagehandtag	2022-01-10	300,00	300,00
7	1150	Manuell Kantpress 100T	Manuellt arbete	P243030	CU512509	Borsthållarhalva KTH 50/51	2022-01-18	14,00	14,00
8	1150	Manuell Kantpress 100T	Manuellt arbete	P243139	TD292002	Fäste Främre Regnh.M. KTF/Ke	2022-01-11	60,00	60,00
9	1150	Manuell Kantpress 100T	Manuellt arbete	P243460	EF5170	Sida Förhöjning Fot SEH80/33	2022-01-18	2,00	2,00
10	1150	Manuell Kantpress 100T	Manuellt arbete	P243466	EF5215	Glidskivetriangel Fot SEH80/33	2022-01-18	2,00	2,00
11	1150	Manuell Kantpress 100T	Manuellt arbete	P243496	EH5450	Fäste Axelskydd SEH80/33	2022-01-17	2,00	1,00
12	1150	Manuell Kantpress 100T	Manuellt arbete	P243570	OD2574	Glidskena Skjutreg. Silospj. Fy250	2022-01-17	40,00	40,00
13	1150	Manuell Kantpress 100T	Manuellt arbete	P243747	CU5135	Fästlist för Borste B500	2022-01-13	72,00	72,00
14	1150	Manuell Kantpress 100T	Manuellt arbete	P243764	D032802	Tak Standard DB30T	2022-01-12	24,00	24,00
15	1150	Manuell Kantpress 100T	Manuellt arbete	P243766	D0360	Sida Utlopp DB30T	2022-01-12	84,00	84,00
16	1150	Manuell Kantpress 100T	Manuellt arbete	P243767	D042002	Övre Botten DB30T	2022-04-25	39,00	39,00
17	1150	Manuell Kantpress 100T	Manuellt arbete	P243768	D0430	Golvsveper Plåt DB30T	2022-01-12	31,00	31,00
18	1150	Manuell Kantpress 100T	Manuellt arbete	P243777	D0851	Baksida Utlopp DB60T	2022-01-14	160,00	160,00
19	1150	Manuell Kantpress 100T	Manuellt arbete	P243791	EF0834	Lagerfäste Motor-Inlopp Spjäll	2022-02-17	64,00	62,00
20	1150	Manuell Kantpress 100T	Manuellt arbete	P243977	EH141802	Handtag Huv SEI50/18$	2022-03-18	162,00	159,00

Table A.1: Monitor Data 1

	Planned total time	Reported total time	Emballage type	Quantity/container	Number of containers needed	Numbers of containers needed rounded off	Containers/EU pallet
2	0,5206	0,641666667	300x200x150 mm Låda	58	0,034482759	1	11
3	0,5206	0,591666667	300x200x150 mm Låda	58	0,034482759	1	11
4	1,04	1,266666667	300x200x150 mm Låda	24	3,75	4	11
5	0,698	0,510739722	400x300x200 mm Låda	17	1,882352941	2	6
6	3,59	2,533333333	400x300x200 mm Låda	60	5	5	6
7	0,6442	0,694444444	600x400x200 mm Låda	7	2	2	2
8	1,58	1,325	400x300x200 mm Låda	60	1	1	6
9	0,5446	0,477142778	600x400x200 mm Låda	4	0,5	1	2
10	0,5446	1,938888889	400x300x200 mm Låda	16	0,125	1	6
11	0,5686	0,716666667	#N/A	0	#DIV/0!	#DIV/0!	#N/A
12	0,502	1,483333333	#N/A	0	#DIV/0!	#DIV/0!	#N/A
13	1,5296	1,5	600x200x150 mm Låda	36	2	2	5
14	0,692	1,311111111	600x400x200 mm Låda	17	1,411764706	2	2
15	1,676	2,144444444	300x200x150 mm Låda	30	2,8	3	11
16	1,592	1,85	400x300x200 mm Låda	15	2,6	3	6
17	1,275	1,844073056	600x400x200 mm Låda	18	1,722222222	2	2
18	1,46	0,973333333	300x200x150 mm Låda	130	1,230769231	2	11
19	1,396	2,027777778	400x300x200 mm Låda	22	2,818181818	3	6
20	5,846	5,233333333	400x300x200 mm Låda	27	5,888888889	6	6

Table A.2: Monitor Data 2

Q	R
Number of EU-pallets needed	Number of EU-pallets needed rounded off
0,090909091	1
0,090909091	1
0,363636364	1
0,333333333	1
0,833333333	1
1	1
0,166666667	1
0,5	1
0,166666667	1
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
0,4	1
1	1
0,272727273	1
0,5	1
1	1
0,181818182	1
0,5	1
1	1

Table A.3: Monitor Data 3

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	Count of Ordernumber	Column Labels																					
2		maj																				maj Total	Grand Total
3	Row Labels	02-maj	04-maj	05-maj	06-maj	09-maj	10-maj	11-maj	12-maj	13-maj	16-maj	17-maj	18-maj	19-maj	20-maj	23-maj	24-maj	25-maj	26-maj	30-maj	31-maj		
4	1150	2	1	1	1	3	3	2	3			1		1		1		2		1	2	24	24
5	1151	3	3		2	1		1	2				1	2		1	1	1			2	20	20
6	1152	1	1	2		2	6	4	1	1	10		3	1		2	1				1	36	36
7	1153	2	4	3	6	8	5	10	6	1	10			2	2	1	2	14	1	4	5	86	86
8	**Grand Total**	**8**	**9**	**6**	**9**	**14**	**14**	**17**	**12**	**2**	**20**	**1**	**4**	**6**	**2**	**5**	**4**	**17**	**1**	**5**	**10**	**166**	**166**
9																							

Table A.4: Pivot Table

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6	Supplier 7	Supplier 8
Functions								
Fleet management system	x	x	x	x	x	x	x	x
Natural environment navigation	x		x			x		x
AMR	x	x	x			x		x
Customisable	x	x	x	x	x	x	x	x
Batterylife >8h	x	x	x	x	x	x	x	x
Full charge time <8h	x	x	x	x	x	x	x	x
Load								
Supports EU-pallet	x	x	x	x	x	x	x	x
Supports plastic containers	x	x			x			x
Safety								
Bluespot	x	x	x	x	x	x	x	x
Warning sound	x	x	x	x	x	x	x	x
Bumper	x							
Support								
Office in Sweden	x	x	x	x	x	x	x	
Support avaliable <200km	x	x	x	x	x	x	x	x
Total:	13	11	11	9	10	11	9	11

Table A.5: Supplier comparison

A.3 Interview Questions

Interview Questions Production Manager

- In what type of containers does finished products get packed today in the manual press brake machines today ?
- Who is responsible for moving finished materials from the manual press brakes to warehouse position T11?
- Is there existig packing instructions for all articles in MONITOR G5?
- What will the capacity requirements be in the future at the press brake department ?
- How many operators are there at every shift ?
- Are there any space requirements regarding the forklift traffic or machine operators in place ?
- How does the work priority work in MONITOR G5, can operators choose themself ?
- Is materials moved in MONITOR G5to T11 first and then it is moved by a forklift ?
- What are your thoughts about AGV/AMRs ?
- Do you see any roadblocks or problems with the use of AGVs at Skandia?

Interview Questions Logistics Manager

- How large is the logistics department today?
- How many forklifts are there in the factory?
- How are the forklift operators split up between different departments and work tasks?
- Is there any speed restriction zones or forbidden zones regarding forklift traffic?
- Have the forklift traffic in the factory been analysed and documented before?
- Traffic rules in the factory ?
- What or who decides where material gets stored in the warehouse. Automatic by MONITOR G5or by the operators?
- What is the function of T11?
- Signal system for removal of finished products in press brake department ?
- What are your thoughts about AGV/AMRs ?
- Do you see any roadblocks or problems with the use of AGVs at Skandia?

Interview Questions Supplier & integrator

- What solutions do you have for loading and unloading cargo?
- What are the options for communicating with the AMR system? Does the ERP system need to be involved ?
- What is the required maintenance for the AMR system ?
- How do you usually work with support?
- Is there any required infrastructure to accommodate the system at Skandia Elevator?
- Scalability?
- It security ?
- How is the battery range on your different AMR models ?
- How is systematic failure risks usually handled?

Interview Questions Company A

- How is the AMR used within the company today?
- How are job orders created to the AMR? ?
- What did the implementation process look like?
- Safety and maintenance?
- What are the main benefits, and are there any pitfalls?

Nr	Risk	Probability (1-5)	Consequence (1-5)	Risk-number	Action	Expected outcome	Responsible	Finish date
1	Running out of time to complete project	2	5	10	Define clear scope and timefram	No final solution being created. Opportunity to learn lost	Axel/Filip	2023-06-04
2	Not enough guidance/support	1	5	5	Schedule more frequent meetings	There will be enough support and guidance avaliable	Axel/Filip	2023-06-04
3	Economy does not support the solution	2	3	6	Compare the different solutions	Guidelines changes for budget if depening on the return of investment.	Jerry	2023-06-04
4	Not enough competence about AGVs (inhouse)	4	5	20	Use avaliable resources, cooperation partners and study visits.	There will be enough competence avaliable to succed with the project	Filip/Axel	2023-06-04
5	Environment not suitable for AGVs	3	5	15	Either revise solution or look for possibilities to customize environment	Solution will be desigend with the constraints of the enviroment in mind. Or when needed the enviroment will be customized inside reasonable boundries	Filip/Axel	2023-06-04
6	Uncertainty in data	2	3	6	Own measurments and observations	The data avaliable will give a good representation of reality	Skandia	2023-06-04
7	Lack of scalability in final solution which limits the use of solution in the future	2	4	8	Thorughtly analys the product offers from AGV supplier	The used supplier will be able to deliver solutions that fit many different logistical operations.	Filip/Axel	2023-06-04
8	Not enough competence about AGVs (externally)	1	5	5	Look for more resources	Sufficient resources will be find	Filip/Axel	2023-06-04

Table A.6: Risk analysis

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY