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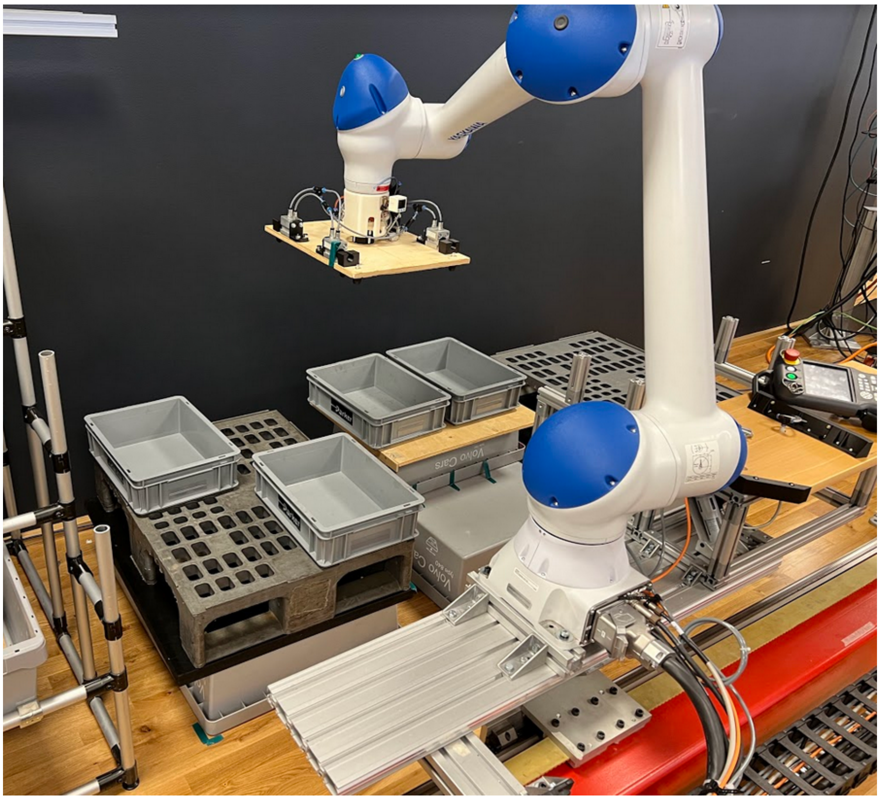

Designing an efficient automated material flow

Master's thesis in Production Engineering

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MASTER'S THESIS 2022

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Abstract

Automation is a key technology that already has been implemented in the industry and is proven to be great aid to boost production capabilities. Most of the literature and previous research has demonstrated the benefits of automation when applied to manufacturing and production. However not as much research has been done using automation as a tool to enhance material handling within a company and material handling overall is less researched than manufacturing. This thesis uses literature, direct observation and data from a current material handling situation as base for the research. Automation is a key technology that can be applied in multiple cases. Different solutions can be used to maximize the positive benefits of implementing automation. Our findings indicate that implementation of automation by the use of AMR and Robot sorting within a material handling process can increase productivity and reduce manual labor needed within the process.

Keywords: Automation, Material Handling, AMR, RFID, Robot, Gripper, SCARCE.

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Lastly we also would like to thank Parker Hannfin and the SCARCE II-project for allowing us to conduct our thesis work at their production site in Trollhättan. Special thanks to the lean coordinator, Lena André for giving us a tour of the factory and providing the necessary knowledge to be able to carry out this project.

Amir Makhkamov & David Ek, Gothenburg, June 2022

List of Acronyms

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

AGV	Automated guided vehicles
AMR	Autonomous mobile robots
KPI	Key performance indicator
KTH	Kungliga Tekniska Högskolan
KRI	Key Result Indicator
PHG	Phrogramming Pendant
RFID	Radio Frequency Identification
SCARCE	Sensible Value Chain through Digitalised Planning, Material handling and Circular Economy

Contents

1
Introduction

This chapter introduces the thesis and presents the background, its purpose and scope. A brief description of the industrial material flow is also provided along with the research questions and scope.

1.1 Background

In the manufacturing industry, the cost of material handling can often account for more than 50 % of the total cost of the manufacturing process [1]. By improving the material handling process, positive results such as reduced cost and increased productivity that benefits the whole production system [1]. More than 50 % of accidents in industries connect to material handling [2]. A well-designed material handling system is necessary to avoid: delays, prolonged production time, and the risk of damaging the products [3]. Additionally, the material handling system design needs to consider the movement of the product within the facility to reduce unnecessary movement. Hence, the material handling system plays a key role for performance in production systems, and improvements to the material handling system are important.

Companies have started implementing automation to improve their material handling process [4]. There are several benefits to implementing automation in the material handling process. With an automated process, companies could increase their productivity as machines could be up and running 24 hours a day. Hiring workers short-term to increase capacity can be challenging. With fully automated processes, capacity can quickly increase or decrease depending on current demand. It is also possible to reduce the workforce to save costs, relocate the employees to other projects within the company or simplify/improve the current manual work situation for the employees [5].

Some prerequisites need to be taken into account and considered when designing and implementing automation within material handling processes. The requirements for successful implementation can be, e.g., incorporating a system that carries out autonomous decisions, cooperation between robotics and autonomous vehicles. Additionally, relevant real-time data needs to be gathered and analyzed from sensors to realize autonomous decisions. Implementation of automation comes at an increased complexity, cost and requires supervision and follow-up. Another vital prerequisite is knowledge, and it is crucial for implementation success that leaders have the nec-

essary knowledge to introduce and use new technology properly. Lack of know-how and complexity during the implementation process is a common obstacle in any scenario with new technology or ways of working, not just automation [6].
The SCARCE-project is a project in collaboration between companies and the technology schools Chalmers and KTH. SCARCE stands for Sensible Value Chain through Digitalized Planning, Material handling and Circular Economy. The project aims to optimize the value chain of materials between companies such as STENA, Bror Tonsjö, Parker Hannifin and Scania. This thesis focuses the material flow between Bror Tonsjö and Parker Hannifin. The Value chain in this thesis will start with the materials arriving from Bror Tonsjö and the material handling processes at Parker Hannifin will be studied for improvement potentials.

Parker Hannifin has around 55 000 workers in about 50 different countries all over the world. Today the company has several plants in Sweden and the plant in Trollhättan is the reference point for this master thesis. The material flow at Trollhättan that will be studied is the delivery and handling of shafts from Bror Tonsjö until they are ready to be assembled. The plant in Trollhättan mainly has the mining and lumber industries as their main customers.

This thesis is in collaboration with Parker Hannifin and the plant in Trollhättan. Currently the material handling flow of semi-finished products from Bror Tonsjö involves a great deal of manual labor and the pallets that the material arrives on have a low fillrate. Currently the material flow at Parker Hannifin involves a great deal of manual labor and a large portion of the total manual work is covered by the transport of materials since there are about 80 pallets that's are going through the material flow every day. Due to this Parker Hannifin is considering to implement automation to remove portions of the manual labor needed each day. The employees have other daily tasks beyond the material handling and the combination of manual labor along with the low fillrate causes more time than desirable spent within the material handling. A detailed view of the current material handling can be seen in Chapter 2 Case Description.

1.2 Aim

Identify the potential of automation to improve lead-times, reduce man-hours within the material processes and increase the fillrate at Parker Hannifin.

1.3 Scope

This thesis only focuses on the material handling within Parker Hannifin's factory that includes the axles that arrive from Bror Tonsjö that are semi-finished and are transported to the processing area (Shaft department). Parker Hannifin receives material from other suppliers but the material handling flow of these products are not included in the thesis. The material flow of semi-finished axles studied in this thesis ranges from the unloading of material from the delivery truck until the material is delivered to the processing area (Shaft department). The handling of material before and after these operations are not included in the thesis work.

1.4 Research questions

To adress the thesis purpose and help guide the research conducted in the thesis, three research questions are formulated in this section. The first question addresses the application of automation from a standpoint of in which processes of Parker Hannifin's material flow it is suitable to apply. The second and third question addresses the performance evaluation of an automated solution. It is important to identify the most suitable processes for automation so that a successful automation implementation can be achieved. Performance measures are necessary to validate that an automated solution yields positive results. Hence the first research question of the thesis is expressed as:

Research question 1:

- Which material handling process is suited for automation and has the greatest impact on the performance of the material flow?

To have the most significant impact it is important to select the proper processes for automation. This will allow Parker Hannifin to have the greatest positive results for future potential investments.

The answer to this question above will provide Parker Hannifin with a better understanding of what kind of processes in their current material handling can be improved with the help of automation.

Research question 2:

- What automation solutions are suitable to use for the material processes identified in the answer to Research Question 1

Since most investments carry downsides such as costs, learning time for employees etc it is important that investments carry enough positive aspects to out weight the negatives. If investment is done by Parker Hannifin to improve their material handling by automation it is very important that the result if this investment has a positive impact on the important aspects of the material handling which in the case for Parker Hannifin is performance.

Research question 3:

- How much does the material handling flow performance improve with the help of the automation solutions identified in research question 2.

By making an investment time and money are usually required and a huge benefit for the investor is if the performance increases drastically. By showcasing the potential performance improvements within the material flow to Parker Hannifin it can give a better motivation and justify the automation investment.

1.5 Thesis outline

In chapter 2 the project method is described and it includes the theoretical work and creation of the concept solution. The method also includes the development of gripper for the demonstrator in the laboratory. Chapter 3 includes the relevant theoretical framework used in this thesis. Chapter 4 presents the concept solution along with the results from the demonstrator at the laboratory. Chapter 5 summerizes the problem description, what procedure was taken to solve this problem and the value of the thesis work. Chapter 6 discusses the theoretical and practical value of the thesis results

2

Material flow at Parker Hannifin

Currently, the material handling at Parker Hannifin mainly consists of manual work. In collaboration with Chalmers and the SCARCE II project, the company wants to investigate the potential of improvements by implementing automation in the material handling flow for the semi-finished axles within the product families F11 and F12. The aim is to increase fillrate, reduce man hours within the material flow and reduce lead times. Bror Tonsjö is the supplier of the mentioned semi-finished axles. All of the incoming materials studied in this thesis is supplied by Bror Tonsjö and Parker Hannifin has full control over how the supplies are delivered in terms of time, quantity etc. Both Bror Tonsjö and Parker Hannifin are working together in the SCARCE II project. As such, the value stream provided to us by Parker Hannifin ranges from the delivery of materials by Bror Tonsjö until the delivery of materials to the CNC-machines. The value stream of the current material flow at Parker Hannifin can be seen in Appendix A.2.

The SCARCE II project aims to replace the current manual material handling processes with improved automated processes at the factory in Trollhättan. To fully evaluate the improvement potentials, Parker Hannifin has assigned two students from KTH (Kungliga Tekniska Högskolan) to conduct a bachelor thesis. Their main focus was identifying potential improvements within the material handling. This master thesis will use the value stream provided by the bachelor thesis made by two KTH students along with direct observation from a study visit at the Trollhättan plant to identify the potential processes within the material handling that have the potential to be automated.

The material that is delivered to Parker Hannifin storage from Bror Tonsjö is delivered on 800x600 mm pallets. The pallet are always filled with four or eight boxes and are sealed by a lid. Every pallet contains four boxes regardless of how many boxes that actually contains material. If only one box on the pallet contains material, the pallet will still be packed with four boxes, three being empty. This is done because the pallet needs sealed with a lid. For safety reasons, the company only allows having two pallets stacked on each other. There are two different boxes, and they can either have a height of 170 or 220 mm. The boxes have dimensions of 400x300mm and can maximum weigh 35 kg, but the company prefers the boxes not to exceed 25 kg. The company receives daily delivery that can vary from 60-80 pallets. The pallets that arrive are placed on a roller conveyor to help avoid overload and work as buffers. See Appendix A.1 for illustration.

The pallets are then picked up manually by staff with the help of a power stacker. They are then transported through two doors that act as a sluice to the goods department, where they are then scanned and labeled by a worker manually. The material is then moved to assembly, “Pick-by-light storage,” or the shaft department called “Torget”. At Torget the pallets have their lid removed in a lid removal process. This thesis will study the material flow categorized as semi-finished gods consisting of shafts that are transported to Torget. For an overview of the current material flow that we studied at Parker Hannifin see Figure 2.1 below.

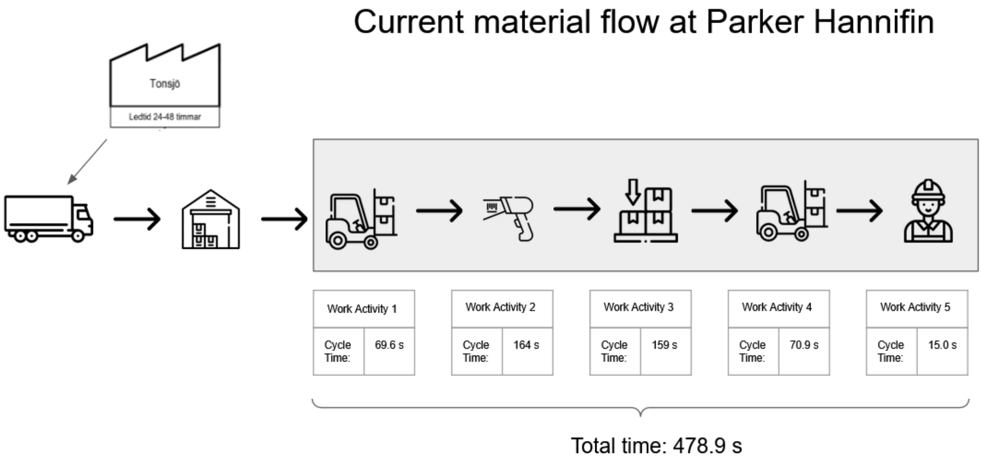

Figure 2.1: Current material flow at Parker Hannifin

The fillrate of the pallets is currently distributed 55 % of four boxes, 4% of three boxes, 17% two boxes, 22% one box. The lower height box variant only consists 6-7% of all boxes. This is visualized in Figure 2.2.

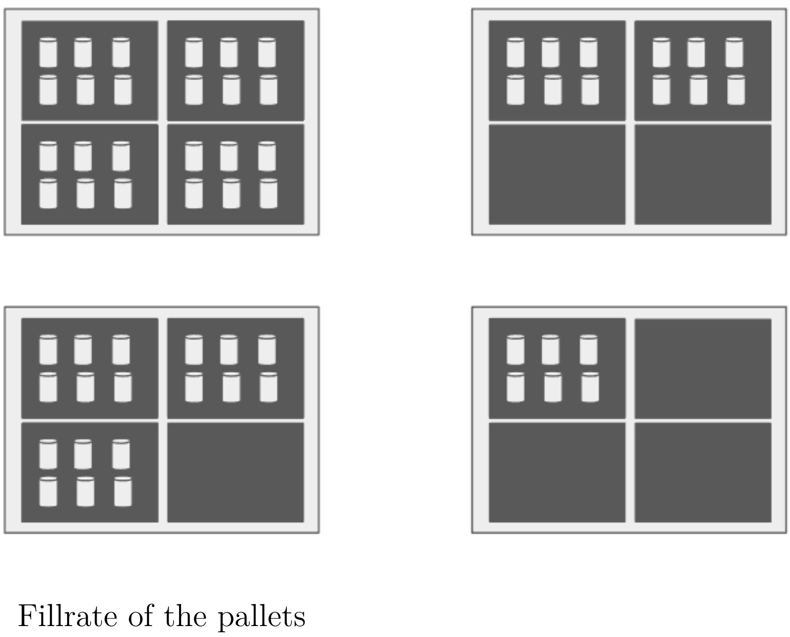

Figure 2.2: Fillrate of the pallets

Following Table 2.1 show the working time in seconds for each activity that occur within material handling.

Table 2.1: Measured work activities during material handling

Measuring occasion	1	2	3	4	5	6	7
Work activity 1	89	75	79	68	66	45	65
Work activity 2	176	144	192	186	179	125	149
Work activity 3	20	3	43	133	126	128	660
Work activity 4	90	60	54	70	65	100	57
Work activity 5*	15	15	15	15	15	15	15

- **Work activity 1.** Walk and get pallet from roller conveyor with a power tracker.
- **Work activity 2.** Goods department, pick up the handheld computer, receipt report, label the four boxes, place pallet in a certain place for pickup and transport to shaft-department.
- **Work activity 3.** Waiting until the rear lift is "full"
- **Work activity 4.** Drive to the manufacturing area (Torget) (one-way)
- **Work activity 5.** (Estimated). Lid removal process at Torget

3 Theoretical Framework

This chapter provides an overview of the relevant theoretical framework used in this thesis. This chapter brings up the important technologies used in the concept solution and explains why they are important for the concept solution to work. The chapter includes information regarding RFID, Automation, Grippers, KPIs and Vision Systems. The information helps to understand the case description, answer the research questions and the development of the concept solution.

3.1 RFID

Parker Hannifin is currently implementing and testing the possibilities with RFID-technology and this is why this section contains information about RFID-technology. The goal for Parker Hannifin is to have a integrated RFID-system in place by fall 2022. In our concept solution we assume that a working RFID-system is already in place. RFID is currently being implemented in the material handling flow and is expected to be working before the implementation of the concept solution, it is not part of the concept solution but a pre-requisite for it to work properly. Having a working RFID-system is necessary to remove the current manual scanning and labeling process and is a key component for development of the concept solution.

3.1.1 RFID functionality

RFID stands for Radio Frequency Identification and describes a system of identification where an electronic device (tag) that uses radio frequency or magnetic field variations to communicate is attached to an item. This is combined with a device that can recognize the presence of this electronic device known as a reader, which can read and store the information on the electronic device. This reader can then inform other systems of the presence and contents of the electronic device. The information read by the reader is often sent and stored on a server [7].

There are different types of RFID solutions and they can differ heavily depending on the use of an active or passive tag. A passive RFID tag is a batteryless tag. Because a passive tag has no internal power source, it is instead powered by the energy transmitted from an RFID scanner [8]. This means that they on average have lower reading distance than active tags and the reading distance is mostly dependent on the power transmitted from the reader to the tag. However this type of passive tag is often much cheaper than the active version and has a longer life-expectancy [7].

The active RFID tag comes equipped with its own battery and internal transmitter in the form of a beacon or transponder. This means that an active tag is able to continuously transmit signals to an RFID reader on longer distances. This makes tracking the items in real-time much easier and on much longer distances possible than with a passive RFID tag. However the active RFID tags are more expensive than the passive tags and have shorter life-expectancy [7].

The main goal of commercial RFID systems is to automate and enhance asset management by providing global asset visibility. This ability of RFID systems finds various applications in diverse fields such as supply chain management, personnel tracking robotics and many more. The potential of the RFID system is mainly due to the numerous advantages that the technology possesses over traditional identification systems such as barcodes [7]. Some of the advantages are:

RFID tags can be read at much greater distances than barcodes. There is no need for a line of sight between the reader and the tag. Multiple tags can be read at much higher rates. RFID tags have large memory which allows for a lot of information to be stored.

However RFID technology does not come without technical challenges. Implementation of RFID technology comes with its own set of obstacles and challenges, both overall and individual and specific to the scenario. It is important to overcome these challenges to achieve the performance needed. Some examples of challenges are readability, the ability to correctly read multiple tags with 100% accuracy rate. This is especially important if multiple tags are in circulation as reading the correct tag and getting the correct information from each tag is crucial [7]. There are also design challenges to think about such as the size and placement of the tag on the items. This is to be able to be read correctly while also not hindering the ability to work on the products or take up unnecessary space if the tag is placed on a box which could reduce the number of articles being able to be placed in the box.

A common problem with RFID is the lack of a well-defined read zone. This means that there is no specific zone in which the reader is able to have a 100% read rate and outside have a 0% read rate. Using a passive RFID tag the distance is heavily reliant on the power being put out from the receiver as such the readability drops off with distance. Orientation also plays a huge part in the use of passive RFID tags. A case study shows performance losses already at a 30 degree angle and a massive loss in performance at 60 degrees [7]. Performance in this case was measured as the distance the tag could be read at 100% accuracy. This shows that orientation and placement of tags on the boxes could play a huge role in what RFID solution a company could implement as limitation to tag size and placements on items could reduce the readability by a lot [8].

3.1.2 Key Operational Parameters of RFID systems

The performance of an RFID system is often measured in two different groups, range and data rate. To control these different groups parameters such as operating frequency and transmit power can be adjusted by the user. The most common deployed tags are active and passive tags operating in the ultra-high frequency (UHF) bands. The higher frequency range allows for greater reading distance while also providing faster information transfer than the lower frequency range [7]. For this to work there has to be a power source of some sort. In the case for the passive RFID tag the power output from the reader also has to be strong enough as the reader has to energize the passive tag for it to be able to respond and send information back to the reader. In the case for the active RFID tag the internal battery in the tag has to be strong enough to power the beacon enough for it to be detected at distance.

Both the frequency in which the tags and readers operate and the power source in either the reader or tag can be changed to allow for variation in operating distance. It is also worth noting that a UHF passive tag will never be able to operate at the same distance as a UHF active tag regardless of the power input. The boost in signal power that a UHF active tag gets due to the internal battery can help to overcome materials blocking the signal in cases where the tag has to be put in “less favorable” places on items [7].

3.1.3 RFID and security

Security is an important aspect to consider not only when implementing RFID but in general to prevent threats and information leaking to wrong receivers. In a RFID system there are two different kinds of threats that can disrupt the process and cause a risk for the user. These two kinds are physical and channel threats [9]. A user needs to carefully address both of these threats when implementing a RFID system.

The physical threats are those threats that use physical means to attack the RFID such as disable tags and modify their content. An example of these could be to remove a tag from a more expensive item and put it on a much cheaper one. The RFID reader will still register that an item is incoming of the expensive kind but in reality the tag has been moved to a cheaper one which is the incoming item [9]. Damaging the tag or antenna is also a form of physical threat that can hurt the RFID system. This damage could also occur involuntarily during a shipping process for example which means that the tags need to be protected against the environment that they are used in.

The other category of threats is channel threats. These refer to attacks targeting the channel and reading of the information sent by the tag to the reader [9]. An example of such a threat is eavesdropping. This means that the information sent from the tag to the reader is also retrieved by another source that is not intended to receive this kind of information. This could be used to determine the contents of packages and the value of the items inside and be used in other ways than intended. Another way the channel threat could work is via skimming. This means that a cloned tag is made that imitates the original RFID tag. The cloned RFID tag could then be applied to another item to replicate the original one. If this tag is placed on an empty box and the real box is stolen the RFID system would not notice that anything is wrong and the crime will not be discovered until the box is opened. This could also be used to gather sensitive information about locations for delivery, value of contents, personal information about the sender, receiver and driver/delivery method.

3.2 Automation of production and material handling processes

This section provides important information about current automation implementation in material handling. To successfully implement an automated solution sufficient background knowledge is required within the area. Automation is a common solution for many companies to improve their current processes. The concept solution that is developed in thesis utilizes this information to properly identify and select the most appropriate automated solutions for this specific case.

To improve performance, reduce man-hours within the material flow and reduce running costs the implementation of automation is a common solution. Many companies are currently using automation to help operators and reducing the amount of manual labor that is needed weather it be manufacturing or material handling processes. Currently the world is moving towards a more automated society but it is very important to know which automated solution that can have the biggest impact on performance as usually the time and investment cost that comes with automation as a drawback does not allow for investments in several different solutions. It is very rare for companies to invest in multiple automated solutions and compare them against each other in a real-life scenario, most of the comparison should be done before investing to find the best solution without having to actually implement the solutions itself within the factory.

Industry 4.0 is a hot topic for manufacturing industries and in the academia. It was introduced by the German federal government as one of the key initiatives of high-tech strategy in 2011 [10]. Industry 4.0 is often characterized with increased productivity, increased levels of operation efficiency and automation [11]. Technologies from Industry 4.0 that are frequently mentioned in literature connected to material handling are the integration of systems, such as Internet of Thing (IoT), which would allow objects i.e. RFID, sensors and automated guided vehicles interact with each other via wireless communication [10] [11] [12].

The general concept of IoT technology is "that every device has access to to the Internet and is abble to collect or distribute information over the network [13].

According to Efthymiou and Ponis, there are five technologies that will have a significant role in making future logistics tasks being fully automated and they are following: autonomous vehicles intelligent robots, RFID technology quick response codes, sensors conveyers, smart devices and Cyber-physical systems (CPS) [11]. They further mentions the current demands within logistics systems require reduced inventory levels and fewer working hours. The changes that will improve material handling and the in-house logistics are done with help of Industry 4.0 technologies; AGVs, robotics, RFID and autonomous decisions and configuration of material handling systems [11].

Implementation of the these system are done to improve the company's manufacturing flexibility, so that the company has the ability to adapt quickly to the design changes that are made from the customers [14]. It is here where the previously mentioned technologies such as automated guided vehicles provide this ability and promote profitability. It is shown that when utilizing AGVs with IoT technologies such as RFID, it can provide efficient and accurate monitoring of objects [15]. There has been significant advancements during the last decade in areas of goods movement and order picking within warehouses, especially with AGVs becoming more autonomous and picking robots. These technologies in combination with each other the future for intralogistics and warehousing, where little to no human involvement would be required [15].

3.3 Automated guided vehicles & Autonomous mobile robots

Companies in the manufacturing sector spend time on material handling, and transportation can be as much as the time used on the value-added processes. The number of employees assigned to the material handling, can account for approximately 25 % [16]. This is why solutions that automated transportation within the material handling are interesting to explore further because they can reduce not only the employees assigned to material handling but also reduce costs.

Automated guided vehicles (AGVs) have been around since the 1950s and have become a key component for intralogistics. As previously mentioned, AGVs' primary areas of application lie within intralogistics, for instance, execution and optimization of internal goods and material flow and logistics [17] [18]. AGVs' purpose is to transport goods from one place to another, and they are usually designed to carry heavy loads. They are also well suited for repetitive flow [19]. When transporting goods, the AGV follows a specified pathway. Implementing AGVs has several potential benefits, such as reduced personnel that are assigned to transporting goods and better-organized material and information flow [18]. The implementation and use of AGVs are most common in manufacturing plants. They are used in several applications such as transportation of raw material, kitting, transportation of semi-finished products, transporting finished goods to the warehouse, or transport material to assembly stations [20].

AGV navigation is evolving, and multiple options are currently available, for instance, there is a low-cost option that uses wires, or magnetic tape, and lastly, laser guidance navigation [21] [16]. All of the navigations options require the AGV to follow rigid guide points. The AGVs are typically pre-programmed and follow the rules that are programmed, and there is also little onboard intelligence for decision making [22]. The AGVs can detect an obstacle in front, but the robot cannot navigate around it. The AGVs are currently, therefore, only able to stop and wait for the obstacle to be removed [20].

There are several differences between AGVs and manually driven vehicles; for instance, the AGVs can orient themselves without being directly controlled by an operator, they are integrated into their surroundings and can communicate on-demand with other neighboring systems [18]. These functions increase productivity and efficiency[21].

The challenges with implementing AGVs can be connected to the adaptability to handle changes in layout and being able to operate in a dynamic environment [22]. Another challenge with the AGVs is that they can stop and wait for the object to be removed. However, with the recent trend of improvements in vision-based technologies and data analytics, such implementation can drastically improve the AGVs [20].

Autonomous mobile robots (AMR) is another example of technology that is used to automatize the transportation of goods and material that has also been integrated into the industry environment [22]. The AMRs and AGVs are very similar in terms of having little or no intervention with humans for their movement [16].

The difference between an AGV and AMR is that AMR uses computer-based vision to navigate through its surroundings[16]. Another example of the difference is that when implementing AMR, the environment does not need to be altered compared to AGVs that need, e.g., permanent wires to navigate [22]. The navigation here is done by a map, which can be constructed either by a pre-loaded facility drawing or by on-site scanning of the facility [16]. AMRs are much more flexible than AGVs when the operating environment quickly changes. Another difference between AMRs and AGVs in their decision-making. The AGVs have a central unit that takes control of decisions such as routing and dispatching, compared to AMRs that can communicate and independently negotiate with, e.g., machines and systems i.e., enterprise resource planning, and thereafter take decisions themselves [17]. The goal of AMR is to make decentralized decisions so it can react dynamically to demand and, i.e., optimize itself.

3.4 Grippers for robotic manipulators

When it comes to implementing an industrial robot, the gripper is one crucial part that needs to be considered because of its importance to manipulate an object. Gripper's design is also important to keep in mind because it can affect the throughput time, system reliability, and compensate for robot inaccuracy [23].

There are three different classifications for grippers depending on their actuating principle of the grasp and they are the following: mechanical, vacuum or magnetic, and universal. The mechanical grippers utilize fingers to grasp the object, the vacuum utilizes a vacuum to grasp the object, the magnetic utilizes an electromagnetic force, and lastly, the universal grippers consist of multiple fingers that imitate the human hand [24].

When designing a gripper there are several things that need to be taken into account, for instance, the mechanism synthes,the optimization of an index contemplating the factors included in the grasps, the gripper sensors and the object's trajectory. The weight, material, and shape of the object that is considered to be manipulated are other important factors that need to be taken into account. There are several different actuators such as linear pneumatic, rotational pneumatic and electrical actuators. The actuators task is to create the closing/opening motion that is used for grasping the object [24].

3.5 Key performance indicators for material handling processes

3.5.1 Work organization around KPIs

Key performance indicators (KPIs) are those indicators that focus on the aspects of organizational performance that are most critical for the current and future success of the organization. KPIs are rarely new to the organization. There are seven characteristics that define what a KPI is [25]:

Nonfinancial - The measurement of the indicator should not be able to be expressed in dollars, euro etc. When financials or money is included the measurement is a result rather than a KPI.

Timely - The performance should be measured often and preferably on a daily basis. It is hard to motivate a KPI if it is not being constantly monitored.

CEO focus - All KPIs make a difference; they all should have the CEO's constant attention due to their importance.

Simple - A KPI should tell you what actions need to be taken and provide a simple output that everyone involved understands the meaning behind.

Team based - A KPI is deep enough in the organization that it could be tied to a team, department or workforce. One person should not be responsible alone for a KPI.
Significant impact - A KPI should affect one or more of the critical success factors

for the organization. Improving a KPI should have a positive effect on success for the organization.

Limited dark side - Before becoming a KPI, a performance measure needs to be tested to ensure that it creates the desired outcome. Measuring something that does not create a desired outcome is useless.

There are other indicators that can be used in an organization along with KPIs and these are KRIs (Key Result Indicators). There are several differences between KRIs and KPIs and it is very important to know how and when to use each one. Compared to the KPIs the KRIs can be financial and can such be expressed in dollars/euro for example. The measures of the KRIs are also performed less frequently and are reported more as a summary of progress rather than a performance measure. Usually only one person (the CEO) is responsible for the KRIs and it does not tell staff or management depending on the outcome exactly what needs to be addressed to change the outcome of the KRI.

Many organizations have operated with KPIs and have found out that they made little or no difference in performance. It is very important to define and plan ahead when implementing a KPI to have success. The organization needs to fully understand the value and importance of a KPI for it to be successful. To successfully implement KPIs there are seven foundation stones listed below.

Partnership with staff, unions and third parties: To successfully improve performance an establishment of an effective partnership among management, local employees, customers and suppliers are needed.

Transfer of power to the front line: Empowerment of the organization's employees to allow employees to take immediate action to prevent situations that are negatively impacting KPIs such as doubling the truck workers to speed up the unloading of a late material delivery.

Measure and report only what matters: It is critical that only the most important processes are measured and reported and each report should be followed up with some kind of action depending on the measurements taken. There is no idea to report a measurement if no action is taken afterwards, then the measurement could just not have been reported in the first place.

Source KPIs from critical success factors: The KPIs should be taken and directly impact the organizations critical success factors. The purpose of the performance measures is to ensure that the staff members spend their working hours focused on these critical success factors. If performance measures are low it means that the workers' time is spent elsewhere.

Abandon processes that do not deliver: It is important to realize when something is not working out as intended. The same process can drop performance over time due to outdated ways of working, increase in variety that the old process cannot cope with etc. This means new ways of working are developed along with new performance measures and being able to adapt and abandon old ways is very important.

Appointment of a home-grown chief measurement officer: Suitable trained staff members need to be assigned to the measurements as just taking measurements and not acting on them properly will not contribute to success. Performance measurement is not an easy task and often multiple departments can be needed to measure small parts each to contribute to the KPI.

Organization-wide understanding of the winning KPIs definition: Communicating the importance of the KPI and how it affects the organization is very important. Employees must know the importance of the KPIs and know why they are critical to success.

It is important to note the importance of designing KPIs based on the individual organizations needs. There are no such “general” KPIs that should be used in all circumstances of material handling that would fit every organization on the planet. It is important for every organization to identify a winning strategy and develop KPIs based on the organization’s needs. As an example, according to Parmenter an airline company used time as in if a plane was delayed or not as a KPI. If a plane was delayed the senior officer would be notified and would contact the local manager at the airport. This resulted in very few planes being late and this KPI affected all six of the airplanes companies important perspectives which were cost, customer dissatisfaction, environment impact, impact on staff development, supplier relationships and employee satisfaction.

Performance indicators that are commonly used can be divided into different categories. Safety and environment, which includes KPIs such as number of accidents at the workplace, number of alarms and amount of waste generated. The efficiency category includes KPIs such as efficiency of employees, production times and production downtime. Quality is very important in today’s market and some KPIs related to quality are the amount of defects, production losses and amount of products that need rework [26].

3.5.2 Important KPIs for material flows

There are many different KPIs that can be used but the most important thing is to find the right KPIs for the right scenario. It is important to improve the things that matters and are actually going to benefit the investor. Even if an investment has both positive and negative aspects it is important to focus on making sure that the positives out weight the negatives which can be done by focusing on the correct KPIs and trying to maximize these. Within manufacturing in general there are several performance factors that are important, these are amongst others, lead time, flexibility and cost [27].

With the needs and demands from Parker Hannifin we have concluded that the following KPIs are the most important and should be focused on when working with the project:

Lead time - Time total that the material spends from being delivered by truck until being delivered ready for manufacturing at Torget.

Man-hours - The amount of time operators need to spend within the material flow with all necessary tasks needed included in the total time.

Fillrate - Fillrate in which the pallets are being delivered by Bror Tonsjö. The fillrate is connected to the material that is placed the pallet, it is a measurement of the how many empty boxes that are on a pallet. This was an important performance factor by Parker Hannifin and will reduce the amount of pallets needed to be transported every day.

Productivity - The total cost per product within the material flow, this is important as Parker Hannifin wants to reduce the total cost spent on material handling in general.

We find these listed KPIs to be the most important to work towards in this project when presenting a concept solution. By focusing on these four KPIs we can ensure that performance increase in any of these areas will be beneficial for Parker Hannifin and an improvement compared to the current solution that are in place right now.

3.6 Vision Systems

A large problem when using robots is to align the materials correctly so the robot knows exactly where it is to be able to pick it up. This problem is usually solved in one of two ways, the first one is as shown in the demonstrator with exact placements of the material allowing the robot to know the exact location of the material that is due to be picked up. The second solution is to allow the robot to "see" to navigate and be able to identify the location of the materials. In the demonstrator the exact placement solution is used but for the concept solution we are using a vision system to allow the robot to properly pick up the material.

A vision system on a robot is used to make the robot “see” and thus be able to locate the incoming material and pick it up. This eliminates the need for the material that’s being picked up to always be placed in the exact same location. This saves a lot of hassle both when the material is placed by a robot or manually by a human as having to place the product in the exact same spot every time can be very time consuming. A common solution to this problem however is to have fixtures in place that locates the material in the exact same spot every time. With a vision system on the robot it eliminates the need for any fixtures and gives more “room for error” in the placement of materials. This especially helps if the material is placed by another robot as now neither of the robots will require exact placements to make the process work.

The most basic form of vision system is using a one camera or single view option. This means that a camera is typically positioned on the body of the robot and provides a single view on the scene being analyzed. A more complex vision system uses two or more cameras to provide greater information. Having multiple cameras allows the robot to extract depth information of the imaged objects via triangulation for example. Another form of information gain for the robot is visual cues. This is often used when harvesting crops or fruit as the machine vision can separate the fruit from the background and since most fruits change color when they ripe this technique can be used to harvest the ripened fruits only. In the case of the material handling this visual cues can be used as the boxes that are being sorted are all gray and the holes in the boxes where the gripper needs to go can be identified since it will have another color. Colors are typically used in RBG representation. Other cues that can be identified with the vision system are texture and shape. This can be of great use when the illumination conditions vary or if the robot has to handle boxes of different colors for example.

Vision system allows more flexibility for the robot as it can be used to identify multiple types or materials and incase of material swaps there is no need to build and place another type of fixtures compared to using the method where the material needs to align perfectly. A vision system can also be used to detect defects in both the boxes and material itself, a camera can magnify an image and detect defects that the naked eye would probably miss which can allow for detecting defects in an earlier stage and take necessary actions[28].

4
Methods

This chapter presents the methodology done in this thesis to answer the three research questions. The information here helps the reader to understand how the thesis was conducted and how the three researched questions where answered. This chapter includes information on the research process, research design, research quality and ethics, development of an automated solution and development of gripper.

4.1 Research process

During the start of the project, a literature study was done to understand better what automated solutions are currently implemented in material handling and how they work. The value stream of Parker Hannifin's material handling flow was assumed to be provided at the beginning of the project, but it got delayed some weeks.

The introduction of the available resources at the laboratory was pre-scheduled to utilize time and understand what kind of possible resources at the laboratory could be used in the demonstrator. The laboratory technicians provided a general knowledge of how the Yaskawa HC-10 robot work and what kind of grippers there are available. The laboratory technicians also provided a basic introduction to how an AMR in the laboratory worked. The pre-scheduled introduction of available resources in the laboratory resulted in less time was spend when developing the demonstrator. After the value stream was received, it was then analyzed, and a study visit was booked at the Parker Hannifin factory in Trollhättan. The study visit was performed to better understand Parker Hannifin's material flow and its processes, gather necessary data, and consult about potential previously analyzed improvements from the value stream. A concept solution was then developed based on the literature studies, value stream, direct observations, and interviews of employees at Parker Hannifin. The information used to develop the concept solution provided a basis to rank the different automated solutions to each other with the help of a Pugh-matrix.

A demonstrator was then developed from the concept solution in a laboratory environment to understand better how it would work in reality. The demonstrator was also developed to test and evaluate the concept solution's most essential and central function, which is the sorting process. The sorting process was developed in the laboratory, where the Yaskawa HC-10 robot would pick up the unsorted boxes and sort them on an empty pallet. The operations tested were picking and placing the boxes from one pallet to another. Additionally, the gripper's performance was also tested, i.e., how it aligned and grasped the boxes. The available grippers (finger and vacuum) at the laboratory were not suitable for picking and placing the boxes from Parker Hannifin, and therefore a new gripper was designed and developed. The gripper's design and development were done with the help of litterateur about grippers for robotic manipulators and laboratory technicians. The gripper was then manufactured with the help of additive manufacturing. A test was also conducted to see how it performed, including testing how it aligned with the box and the grasping ability. The new gripper was then attached to the picking robot available in the laboratory, and the demonstrator was performed.

4.2 Research design

To answer the three research questions, a research design was developed to address the questions. The research design consists of a literature study, data collection from Parker Hannifins's material flow, development of concept solution, and development of laboratory demonstrator. Literature study helped to build an overview of what kind of important technologies there are in the industry and material handling. Data collection from Parker Hannifin's material flow provided a better understanding of Parker Hannifin's situation and their processes. The data collection consisted of a study visit which included a guided tour of the factory, were direct observation and informal interviews with employees further helped to grasp Parker Hannifin's material handling flow:

- Which process in the material handling is suited for automation and has the greatest impact on the performance of the material flow.

Development of a concept solution was then done where the different automated solutions were weighted to each other with the help of a Pugh-matrix. Pugh-matrix was selected because it is a famous and frequent tool used for engineers to weigh different concepts with each other. Consultation with the laboratory technicians also had an influence of the development of the concept solution.

The approach that took place to answers the seconds research question was done by comparing the developed concept solution with the current material handling flow at Parker Hannifin.

- What automation solutions are suitable to use for the material processes identified in the answer to Research Question 1

Times for current work activities was given to us by the lean coordinator of Parker Hannifin and served as a base to compare to concept solution against. After the development of the demonstrator the operating process were monitored and working time was measured. This was used as a base for the estimated time of the robot sorting process in the concept solution. In the demonstrator a very slow speed was used for safety reasons and it is assumed that the working speed of the robot used in the concept solution is at least twice as fast. The transport times by the AMR in the concept solution was based on the times of the current situation. The total estimated mean value time of the concept solution was then compared to the total mean value time of the current process. The comparison focused on the three KPI's lead time, man-hours and fillrate. As seen in the results a significant improvement could be achieved.

- How much does the material handling flow performance improve with the help of the automation solutions identified in research question 2.

4.2.1 Literature study

A literature study was conducted to gather further information about RFID-systems; since the RFID-system is currently under development, and its potential for implementation at the factory is currently unknown. RFID-system potentials are based on the results from this literature study and not the current benefits at the plant in Trollhättan. The developed concept solution for Parker Hannifin's future material handling flow considers the RFID-system as already implemented. RFID-system was researched because it could eliminate manual tasks such as scanning and labeling at Parker Hannifin's plant.

The Literature study was also conducted on automation of production and material handling processes, KPIs, gripper technology, and vision systems to gather sufficient background knowledge. The research helped to understand better what automated solutions are currently implemented in material handling, how they work, and in what areas, i.e., transportation and sorting. The technology's potential, limitations, and conditions for successful implantation were also researched. For example, RFID has the potential to read and store information from a long distance, but i.e., need to have tags directly placed on the boxes.

With the knowledge gathered from the literature study, it was then possible to identify what kind of automated solutions had the most significant impact in material handling. This information was then used to identify what specific automated solutions were suitable and would greatly impact Parker Hannifin's material handling flow. The development of the concept solution used this information as a basis.

Literature study helped to go further into detail on which specif automated when ranking them against each other. The concept solution utilized the literature study to develop and design a solution for Parker Hannifin's specific case.

4.2.2 Data collection from Parker Hannifin's material flow

To get a basic understanding of the case and the current material handling process at Parker Hannifin interviews were conducted with members of the SCARCE-project both working at Chalmers and at Parker Hannifin. The purpose of this was to identify potential automated improvements in the material handling process. To further help getting an understanding of the current situation and potential of using automation in the material flows, a study visit was made to the factory of Parker Hannifin located in Trollhättan. This included a guided tour of the factory which included direct observation and informal interviews with employees responsible for the material handling process. Time studies were conducted during the visit to measure how long different processes within the material handling took and other relevant data was provided by the Parker Hannifin personnel. Informal interviews were conducted to better understand the Parker Hannfins operations on a holistic level, discuss their operations and challenges at Trollhättan, consult and suggest on potential improvements. The direct observation took place during the study visit at the Trollhättan factory and was done to see and experience the processes in person, gather required data for their processes and to better understand their current operations and challenges they are facing.

During the study visit to Trollhättan Parker Hannifin showcased their RFID-system that was currently under development. The RFID-system is supposed to substitute the manual scanning of products that is currently a large part of the material handling. For this master thesis we agreed together with the SCARCE-project members that along with our automated design the RFID-system will also be implemented and our work with a new design of an automated solution is based on that a functioning RFID-system is already in place. In the study visit to Trollhättan we had interviews with both a lean coordinator who oversees the project and with a process engineer who is working with the RFID-implementation. During the tour at the factory we met several employees who also talked about their way of working and how they would solve common problems that could occur throughout the day and week. Major findings from the study visit was the potential of automated transport and some kind of automated sorting solution to handle the low fillrate on the pallets by combining articles together as the pallets contained a lot of empty boxes.

4.2.3 Development of the concept solution

The development of the concept solution was conducted with the help of gathered information from the literature study and the selection of appropriate automated solutions with the help of Pugh-matrix. The information from the value stream, data collection, and consultation with the laboratory technicians influenced the development of the concept solution.

To get a general idea of possible improvements and where they might suit the value stream delivered to us by Parker Hannifin was studied along with direct observation from the study visit at the plant in Trollhättan. The different processes along with their operation time in the current flow was analyzed. Here we identified the most time-consuming processes and weather they were deemed necessary for the material flow to work or if they could be removed entirely. After analyzing the processes, the scanning and labeling process along with the transport were the two most time-consuming processes. The problem with these two processes was discussed with the lean coordinator from Parker Hannifin, Labratory staff and members of the SCARCE-Project.

It was agreed that automation would be a potential improvement and suitable to use in these two processes. A automated transport would be used to remove the manual transport needed and the inclusion of allowing pallets with mixed articles would reduce the amount of incoming pallets each day but also some kind of sorting process would then be needed to the mixed pallets for use in the manufacturing. This sorting process would then replace the current scanning and labeling process which would disappear due to the implementation of RFID. Parker Hannifin already is working in the implementation of a RFID-system and the development of the concept solution assumed that a working RFID-system is in place.

There are many different automation solution and most appropriate ones had to be selected for these processes. By conducting a literature study information about common automation solutions for this type of problems were found. These solution were weighted against each other in a Pugh-Matrix to determine the most suitable solution for these two processes. The results of the Pugh-matrix can be seen in Figure 5.1 and by using the winning solutions the concept solution was developed and agreed upon after discussions with members of the SCARCE-project. The final concept solution would consist of transport by AMR, sorting process by robot and limiting the manual labor needed within the material handling process to removal of the lids. The results of the concept solution compared to the current solution can be seen in Chapter 5, Research Question 3.

4.2.4 Development of laboratory demonstrator

Parker Hannifin's current limitations were considered but did not hinder when designing the demonstrator. The demonstrator was built to test and evaluate its performance based on the future material handling concept at Parker Hannifin. The demonstrator was built with the help of consultation and supervision of the laboratory technicians. It was developed in the laboratory to test and evaluate the most critical and central function of the concept solution, which are the following: testing the gripper's grasping functionality, i.e., the performance of picking and placing boxes. Another reason why the demonstrator had significant importance was testing the robot control. The testing of robot control was done to evaluate the robot's limitations and possibilities. Performance measuring data, speed, and time, from the demonstrator, were also gathered to compare the measurements to the present material handling flow. The gathered knowledge of the demonstrator helped answer the last research question about how much the concept solution could improve Parker Hannifin's current material handling flow with the help of automation solutions.

4.3 Development of an automated solution

The aim of the project is to identify which process steps of the material handling that is suitable for automation. To accomplish this we studied the value stream provided by Parker Hannifin along with a study visit to the plant in Trollhättan. During the visit it became clear that to accomplish Parker Hannifin's needs of reducing man-hours and increasing the fillrate of the incoming pallets within the material handling, different automated solutions could be applied. During the study visit we used direct observation and time measurements to localize where potential efficiency could be improved. The results of this study showed that transport of material between delivery and production processes were very long and many pallets had to be shipped due to the low fillrate. Parker Hannifin expects to have a working RFID-system in place in the future which means that the current manual tagging process will be removed. This was taken into consideration when selecting viable automation solutions.

To solve the two problems mentioned above we identified that automation could be applied to two processes. The automated transport solution is to reduce the man-hours needed within the material handling as a large chunk of the total time is material transport by manual lift as seen in the direct observation at Trollhättan. The automated sorting is to allow pallets to be able to carry different articles and thus increase the fillrate. These pallets then need to be sorted so the correct material for each article ends up in the correct spot. The automated sorting process should allow the man-hours to stay the same as today's scenario as no extra man-hours will be added to cope with the sorting process that needs to be in place when the pallets can be mixed with different articles.

After selecting the most suitable processes in the material handling for automation the correct automated solution had to be chosen. According to the literature, study visit at Parker Hannifin and consultation with technicians at the laboratory common automated solutions were chosen and ranked against each other. In this step we used a Pugh-matrix to rank each automated solution against each other. The key inputs in the matrix were taken from the key performance indicators, literature and constraints that the lean coordinator from Parker Hannifin gave us together with the challenges of implementing each automated solution. The full Pugh-matrix can be seen in Figure 5.1 and shows that the winning solutions are a sorting by robot and transport with the help of an AMR.

After selecting the winning solutions with the Pugh-matrix some additional problems had to be addressed. Both in the concept solution and the demonstrator at the laboratory the robot needs to be able to pick up the material that's being fed to do any type of work or sorting. This meant that a gripper needed to be developed along with a solution so the robot can find out where the incoming material is located. More about the gripper development can be seen in chapter 4.5.

Both the concept solution and demonstrator shared the same problem when using a robot to do the sorting of materials but they were handled differently due to the limitations in the laboratory. In the laboratory the incoming material is placed at a fixed location every time and checked manually and the robot is programmed to always pick the material from that exact spot. This is a scenario that is very time consuming in a real-world scenario and such the concept solution instead uses a vision system on the robot to acquire the information about the material location. There are multiple pros and cons with using a vision system and for the demonstrator the choice was made to not include it. More information about pros and cons and how the vision system would work in the concept solution can be seen in chapter 5.

4.4 Research quality and ethics

The use of several sources of evidence helps to strengthen a case study. According to Yin, there are six sources of evidence: documentation, archival records, interviews, direct observations, participant observation, and physical artifacts [29]. Some of the six sources of evidence were utilized, such as direct observation, documentation, interviews, and participant observation. Furthermore, Yin mentions the importance of research design so that other researchers can follow through with the same procedures and arrive at the same findings and conclusion [29].

From an ethical point of view, one concern in this thesis that needs to be highlighted when implementing automation is the reduction of man-hours in material handling. The concern can be interpreted as the removal or firing of staff assigned to work in material handling. One counterargument is that the intention of implementing automation here is not to fire the staff but instead re-assign the work tasks to the employees where they are more needed. Parker Hannifin confirms this idea because this project aims not to terminate the employees in material handling but instead allocate them to a more meaningful tasks in the factory.

4.5 Gripper development

When it came to the use of gripper, research was conducted to get a basic understanding of the theory, i.e., what sorts of grippers there are available and what needs to be considered when designing and developing a gripper. Patrik Fager and Sven Ekered were the two laboratory technicians that further provided that knowledge. They also introduced the available grippers at the laboratory, and demonstrated how they worked.

Unfortunately, the available grippers at the laboratory which were fingers and vacuum, were not suitable for lifting the boxes from Parker Hannifin. The available grippers could not grasp and lift the boxes directly from above and could only drag the box by the edge, which was unsuitable for stability point of view. Consultation with the laboratory technicians provided a significant influence when designing and developing the gripper. The general idea was to develop a gripper that could go through the holes on the upper edges of the boxes used in the case, then grasp and lift the box. Such gripper would be manufactured with help of additive manufacturing process Fused filament fabrication process. See Appendix A.3 for illustration of the where the gripper needed to grasp the box.

Due to new task of designing and developing a new gripper it was decided that the design should be as simplistic as possible and save time in this project. The holes dimensional were 19,75 x 7 mm and the edge thickens was 5 mm, see Figure 4.1 for illustration of the thickness. These dimensions were the basis when developing the grasping mechanism.

Figure 4.1: Thickness of the box

The biggest focus during the development of the gripper was on the grasping mechanism, how the box could be locked in place, and what kind of mechanism that would help to achieve this. For simplicity reasons the grasping tool that would go through the holes and lock the box in place was decided to be shaped as a "hook". The "hook" shape design made it possible to go through the boxes holes but also provided the ability to lock the box in place by moving it linear. From research that was conduced about grippers and consultation with the laboratory technician, the hooks lower part was decide to be rounded off. The reason for this was to make the gripper more efficient and easier to aligned and placed into the holes. The rounded edges also help to self-align with the holes and in turn compensate for robot inaccuracy. Pneumatic actuators where decided to be used for the closing/opening motion for grasping the box because it was a common actuator that is used for grippers and because it was available at laboratory. The pneumatic actuators that were available at laboratory came from company Festo and the type was ADVC-20-10-A.

It was also decided to use a wooden board for installation of the hooks and the pneumatic actuators because it was the easiest solution that still fulfilled the requirements. compared instead of designing and developing a completely new from scratch. The CAD-software Creo Parametric 7.0, was utilized for the developing and designing the gripper, additionally it was used to demonstrate and illustrate how the gripper would look like in reality and how the grasping mechanism would work. A 5/2 monostable valve was used during to control the pneumatic actuators, following by I/O signals that came from the robot to close/release the grip. Following Figure 4.2 illustrates the developed hook for grasping the boxes. An angle bracket was also designed and developed for attaching the pneumatic actuator to the wooden board, see Figure 4.3 of the Angled bracket.

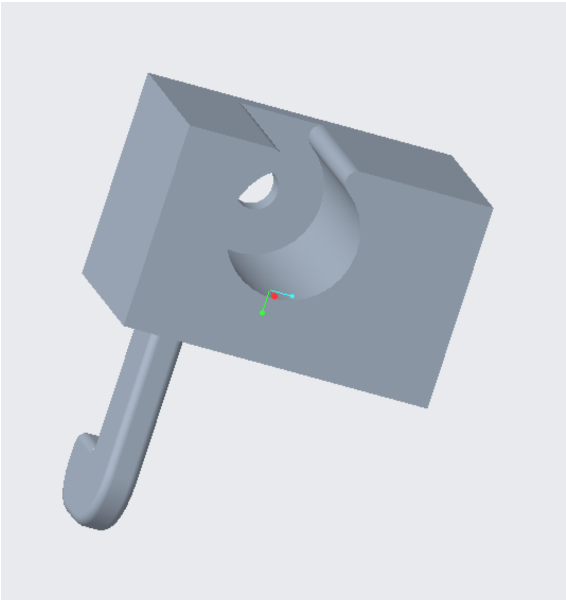

Figure 4.2: Developed hook for grasping the box

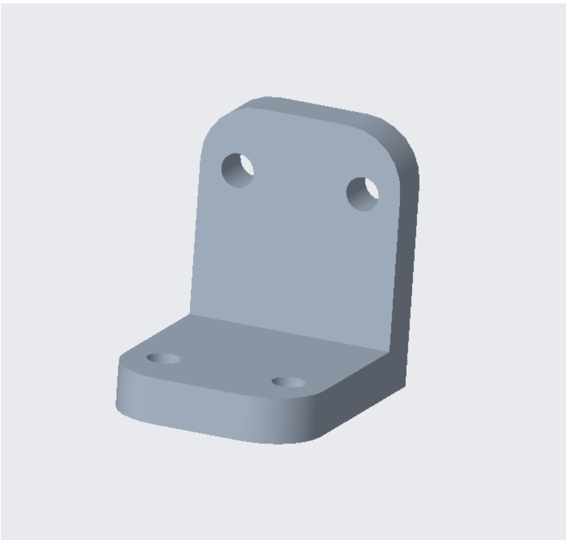

Figure 4.3: Angled bracket

As previously mentioned the gripper consisted of the angled bracket, pneumatic actuator and the hook that were later assembled together in Creo, see Figure 4.4.

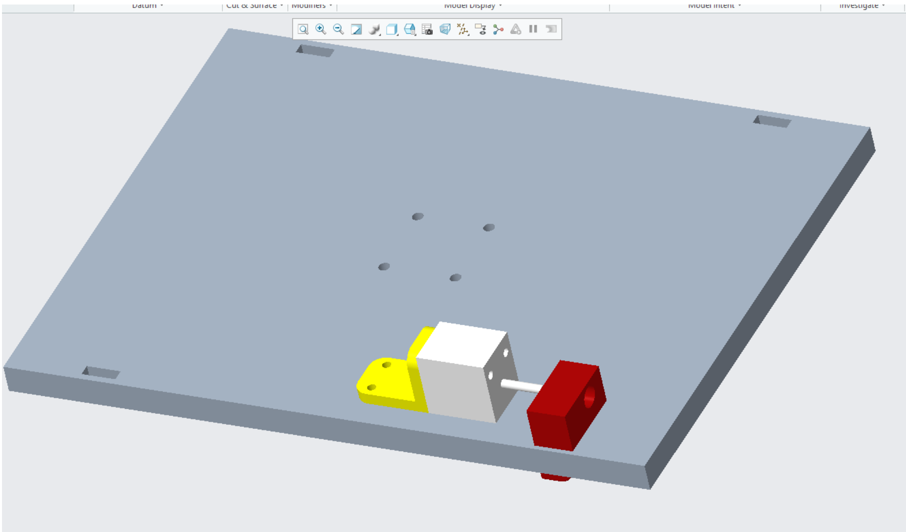

Figure 4.4: Visualization of the designed gripper

The hook and the angled bracket was then manufacturing with help of additive manufacturing using the Fused filament fabrication process available in the laboratory. Markforged Onyx Pro was used to manufacture the parts. Guided "cones" were also developed to further account for robot inaccuracy and provide help for the gripper to be aligned with the boxes and the holes. This removes the need for the robot to be extremely precise and allow for some millimeters in error. See Figure 4.5

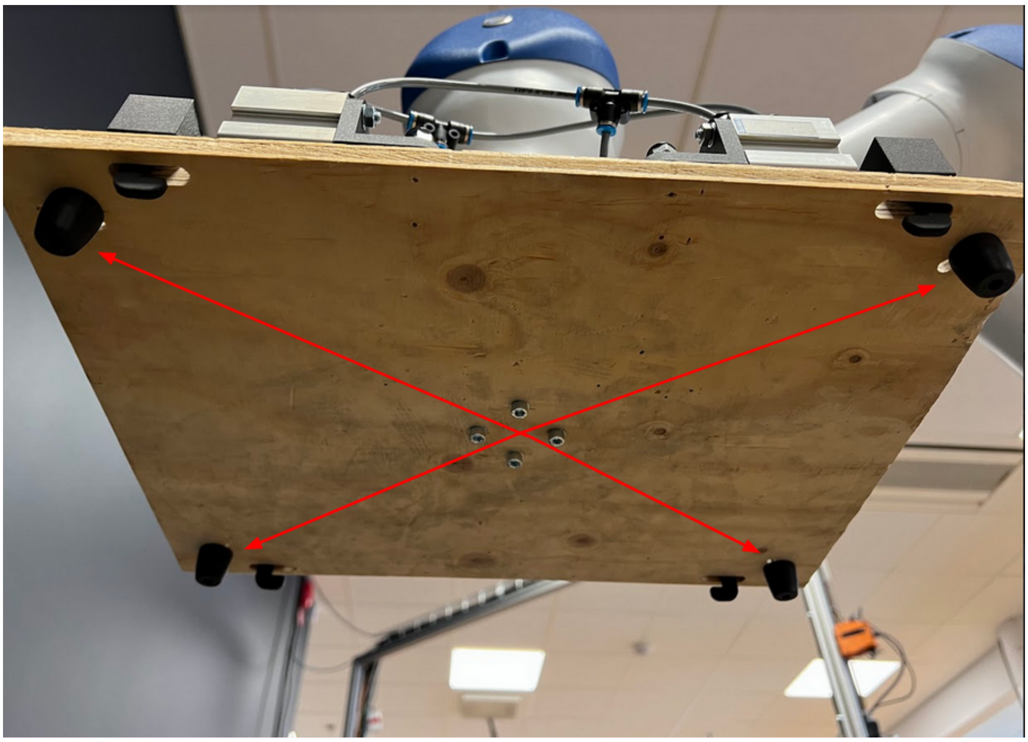

Figure 4.5: Developed guided cones

The Figure 4.6 of how the finished gripper with all of the attached components.

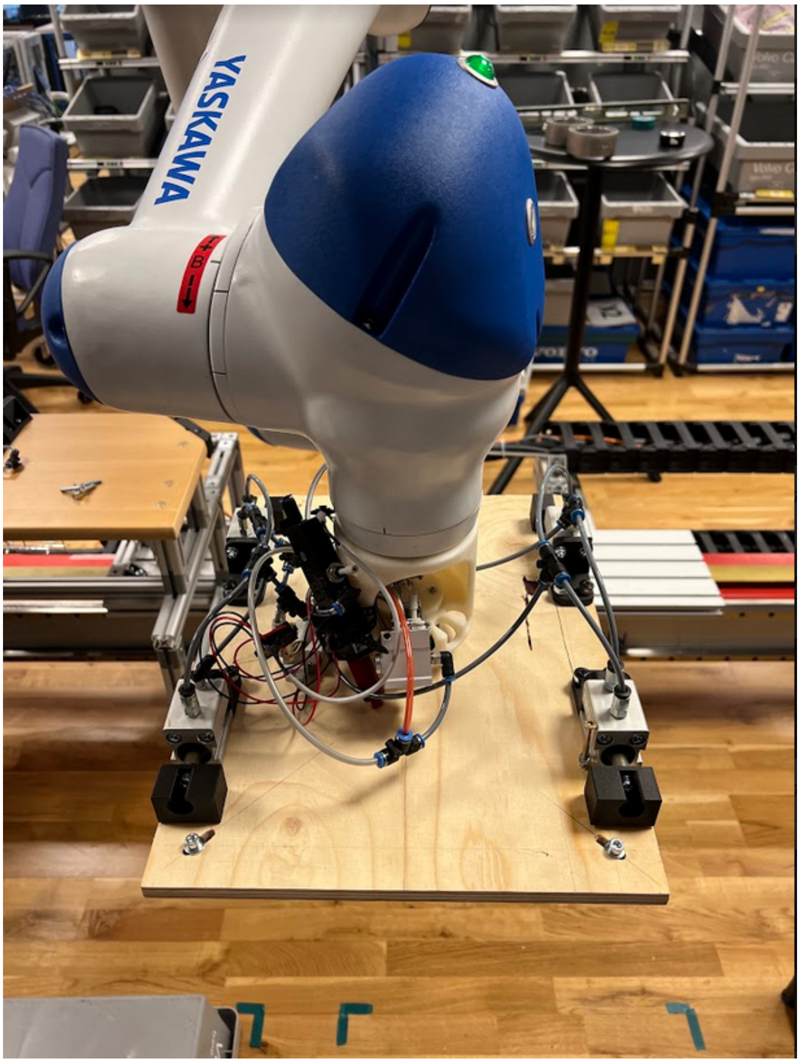

Figure 4.6: Developed gripper

The gripper's ability to self-align itself and grasp the boxes from Parker Hannifin was then tested. The test was performed by placing the gripper above the box and then closing the grip manually. It was showcased that the gripper, with the help of guided cones, was able to help self-align and place the hooks right in the holes. This test helped to understand the importance of designing a gripper that can self-align.

5
Results and analysis

5.1 Answer to Research Question 1

The basic knowledge about automation of production and material handling processes and analyzing the value stream from Parker Hannifin provided a basis for where the potential improvements could be made in Parker Hannifin's material handling flow. In Appendix A.2, the first identified improvements were thought to be within transportation due to the repeated manual work of picking and placing the pallets. The transport processes in the material flow were identified as suitable for automation and would have an impact on Parker Hannifin's material flow performance. The man-hours KPI in the material handling flow will also be reduced thanks to removing the manual transportation process. Another process that has potential is the manual labeling and scanning. This process could be improved or in the best case scenario be removed completely and replaced with an entirely new process.

During the study visit, the lean coordinator informed us that scanning and labeling were performed so that the factory could keep track of the boxes and know where they should end up in the production. The lean coordinator further informed us about the current implementation and testing of RFID technology to eliminate the scanning and labeling operations. Before the study visit, an informal interview was done with the lean coordinator, where Parker Hannifin's desired KPIs were brought up. The identified KPIs consisted of improving lead times, reducing man-hours within the material processes, and increasing the fillrate. With Parker Hannifin's current RFID implementation in mind, an idea came to mind where the fillrate of the pallets could be resolved by having mixed boxes on the pallets so that the number of empty boxes on the pallets could be reduced. As mentioned in Chapter 2, The fillrate of the pallets is currently distributed as follows 55 % consisting of four boxes, 4% of consisting of three boxes, 17% consisting of two boxes, 22% one box. This is visualized in Figure 2.2.

It was identified that an automated sorting solution would help sort the mixed boxes and provide the operator with the desired pallets with the same articles and increase the fillrate of the pallets. The automated sorting solution would have the greatest impact on the performance of the material flow because it reduces the man-hours and increases the fillrate of the pallets in the material handling flow. Additionally, the automated sorting solution, in combination with RFID-system will decrease the lead time in the material handling by eliminating the manual tasks of scanning and labeling. The automated transportation solution would help achieve Parker Hannifin's desire to reduce the number of man-hours by having the staff not operating and responsible for the transportation of the pallets. The lid removal process was identified as not suitable for automation due the need of multiple tools for a robot for example to perform the task. Additionally, the task only takes the operator about 15 seconds to perform and the potential improvement by automating this task was identified as low.

5.2 Research question 2

Currently one of the most time-consuming processes in the material handling is the transport of the material itself. As described in Chapter 2 Case description the current transport is done in 2 "steps" and all transport is done manually by the operators.

5.2.1 Criterias in the Pugh-Matrix

The following criterias was used in the Pugh-matrix to select the most optimal automated solution and the full Pugh-matrix can be seen below in 5.1:

Process speed - Important as efficiency was one of Parker Hannifins main criterias. By reducing the process speed less time has to be spent on material handling and can be spent elsewhere.

Reduction in man-hours - The major criteria to why automation is implemented. The current solution has the material handling involving a lot of manual work which is something that Parker Hannifin wants to reduce.

Long-term benefit - It is very beneficial if the implementation has a positive effect on the company in the long-term so another solution does not need to be implemented in the near future.

Ease to implement - A positive aspect is being easy to implement which can reduce the amount of time needed for the factory to adjust.

Time to implement - Same as above, less time to adjust is important as a huge complex solution is not as easy to motivate.

Cost to implement - Highly costly implementations are hard to motivate as they need to have more positive aspects to make up for it. The less economical cost the better.

Can use existing infrastructure - This is tied to the above criteria as not being able to use the existing infrastructure may lead to further investments in rebuilding.

Fillrate - Also one of the main criteria provided by Parker Hannifin was to increase the fillrate on pallets.

Space needed to implement - Every factory has a space limit and in the current case the space at the material handling flow is very limited and certain large solutions is not possible.

		Importance weightning (1-5)	Transportation			Sorting	
Criteria	Current material handling (0)		AGV	AMR	Conveyor Transport	Robot sorting	Conveyor sorting
Process speed	0	3	(+)	(+)	(+)	(-)	(-)
Reduction in man hours	0	4	(+)	(+)	(+)	(+)	(+)
Long Term Benefit	0	5	(+)	(+)	(-)	(+)	(-)
Ease to implement	0	2	(-)	(+)	(-)	(-)	(-)
Time to Implement	0	2	(-)	(+)	(-)	(-)	(-)
Cost to implement	0	2	(-)	(-)	(-)	(-)	(-)
Can use existing infrastructure	0	2	(-)	(+)	(-)	(+)	(-)
Degree of filling pallets	0	4	0	0	0	(+)	(+)
Space needed to implement	0	4	(-)	0	(-)	0	(-)
TOTAL +			3	6	3	4	2
TOTAL -			5	1	6	4	7
Net Value			−2	5	−3	0	−5
Weighted Total +			12	18	7	15	8
Weighted Total -			12	2	17	−9	−20
Final weighted value of improvement			0	16	−10	6	−12

(+) Alternative better than current solution
(-) Alternative worse than current solution
(0) Alternative equal tothan current solution

Figure 5.1: Pugh-matrix used to "weight" different alternatives against eachother

5.2.2 Automated Transport Solution

The future scenario of Parker Hannifin's material handling will utilize AMR to transport receiving pallets to designated destinations in the factory. In this new scenario, a control system needs to be implemented that is integrated with AMR and the sorting robot that can utilize the RFID data for decision making. The AMR will use the data gathered from the RFID scanner, which will provide orders to where the pallet needs to be transported. Data that a pallet has arrived and is ready to be transported to the new storage area for sorting, information about where the free unloading place in the storage area is for pallet placement. After the AMR is notified that there are pallets available for transportation, it will pick up the pallet and transport it to storage. When the AMR has transported the pallet to storage, it will then place the pallet on a designated area to remove the lid. The AMR needs to have some type of fork, similar to a traditional forklift, to pick up and place the pallets. Within the storage area, there will be a designated area for sorting, a designated area for the placement of pallets that are unsorted and cannot be placed in the sorting area, and lastly, a designated area for sorted pallets. A designated area for sorted pallets is required because 55% of the pallets that arrive at Parker Hannifin are already sorted and complete. The remaining pallets are not full, and in the future, the concept will be combined, which will minimize the total incoming unfilled pallets.

Due to AMR restriction in lid removal, it is therefore necessary that a worker at the factory is notified of the received pallet and can therefore remove the lid and the straps that are attached to the pallet. The worker would need to have a device that notifies this information, i.e., a smartphone or a handheld computer. After removal, the worker will inform the AMR that the pallet is ready to be fed for robot sorting. After the notification from the worker is received, the AMR will then pick up the ready pallet and place it in a designated area for robot sorting. AMR needs to communicate this new information using a control system to the sorting robot to begin to sort the pallet. When the AMR has placed the ready pallet for robot sorting, it needs to be notified when the pallet is empty of boxes so that the empty palled can be removed and provide a new place for other incoming pallets that need to be sorted..

Here, the AMR will provide this additional help with pallet removal. The sorting robot will provide the data to AMR after sorting the boxes and giving orders to remove the empty pallet. The empty pallets will then be removed to place other unsorted pallets for the robot. Sorted pallets will then either be transported to the designated area of sorted pallets or Torget, depending on if the operator in the production requires the material. The operator also needs to have a device that can communicate with the AMR. Therefore, it is essential to highlight the requirement of a platform that can gather data from the incoming pallets received at the factory, the data worker that provides the AMR of ready pallets for sorting, and the data that there is an empty pallet that needs to be removed.

5.2.3 Automated Sorting Process Solution

The sorting process will consist of a robot which sorts the material from the mixed pallets and puts them separated based on articles for the operators to begin the manufacturing process. The robot is located in the concept solution in the goods department area due to the space needed when sorting the pallets. The mixed pallets will be delivered ready to be sorted by the AMR and will be delivered within a designated area but the precision will not be exactly the same every time and the boxes on the pallets will not always be perfectly aligned. To solve this problem the robot will use a vision system to locate the boxes. This vision system needs to be able to analyze a picture in 3D as both the location of the box and pallet along with the depth needs to be known. The boxes come in different heights and can also be stacked ontop of eachother, 2D-driven vision systems can only locate parts/materials on a flat plane which is not enough in this type of material handling.

The vision system will allow the robot to locate and find the boxes and the pallets as long as they are delivered within a designated area. The boxes will be picked up from the pallets via the developed pneumatic gripper which is designed to be able to handle a fully loaded box of 25kg and also handle uneven load in case the box is not full. There is room for a total of 10 pallets for the robot to work and sort from simultaneously and they are all delivered by an AMR. The base concept is that the robot “re-sorts” the pallets from mixed article pallets to pallets containing only 1 article. When the pallets arrive to the robots working area they have already been RFID-scanned and information has been sent via a control system from the RFID-reader to the robot containing information regarding the articles on the pallets, how many boxes there are and where on the pallet each box is located. This is to give the robot full information about the pallet and its contents to be able to perform the sorting process successfully.

Only mixed pallets with at least 2 different article types will enter the sorting area of the robot as mentioned before. These pallets have all had their lids removed beforehand at the storage area. The robot then sorts the pallets to include only one article of axles and a pallet is considered “full” when it has 8 boxes loaded. These boxes that are “full” will be transported from the robot area into Torget and be ready for the operators to use in the production process. One key feature about the sorting is that the robot will prioritize the axles that are next in the production queue so the operators at Torget will receive the materials in the correct order or processing. If there are “full” pallets that have been sorted but are not due in the production for some time they will be returned to the storage area by the AMR and will wait there before being moved to Torget.

The main idea is that the automated flow should prioritize the material that is needed at Torget for production and the AMR/Robot will prioritize these materials when moving and sorting so that the operators at Torget always will receive only the materials needed in the current process. When the machine needs to be set to handle another article type the AMR will pick up this material from the storage and provide it to the operators. In the demonstrator the Yaskawa HC-10 robot is used and has a max load of 10kg. In the concept solution the robot used for the sorting process needs to be able to handle a load of at least 25kg and therefore it is assumed that the robot will be larger than the Yaskawa robot at the labratory. Depending on which robot that is chosen for the sorting process different safety measures needs to be considered such as the working speed of the robot to allow operators to work closely to it without getting injured.

This solution will allow Parker Hannifin to increase the fillrate by combining different articles together on a pallet which will reduce the total amount of incoming pallets. Reducing the amount of total pallets along with the removal of manual labeling and scanning by using RFID-tags will reduce the total lead-time of the material handling. The same amount of material will require less space when transported which allows the delivery truck to load more materials in total or a smaller delivery truck can be used to transport the same amount of materials. The automation processes will also reduce the man-hours spent within the material flow as the only manual labor left is to remove the lids from the pallets. A full view of the sorting process can be seen below in Figure 5.2.

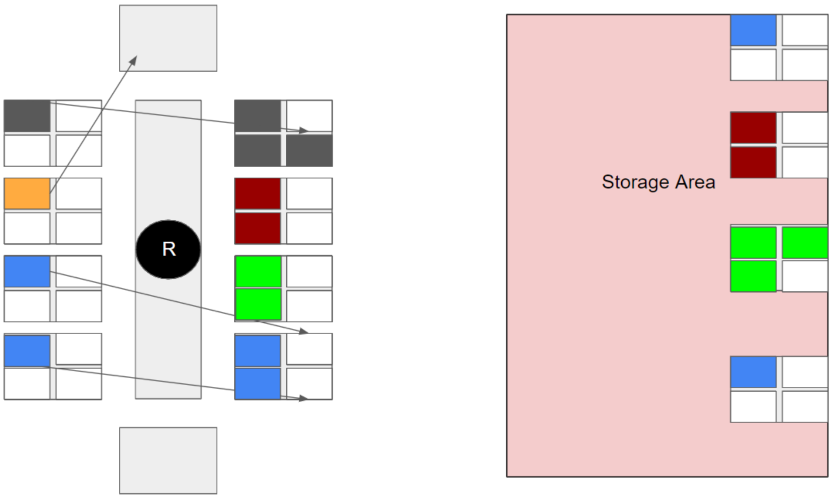

Figure 5.2: Concept solution sorting process

5.3 Research question 3

As previously mentioned, the demonstrator was built on a future concept of material handling at Parker Hannifin with the help of research about automation in material handling and consultation with staff at Parker Hannifin and staff in the labratory. The demonstrator's primary purpose is to showcase that the selected concept solution is feasible. The demonstrator is a simplified solution of the concept sorting solution, where the boxes are empty, and the lid has already been removed. The demonstrator utilizes the Yaskawa HC10, a 6-axis human-collaborative robot available in the labratory. The robot can carry a max load of 10 kg and was equipped with a gripper designed and developed during this project. The robot has a range of 1200 mm and was mounted and integrated into a linear unit, see Figure 5.3. The linear unit provided the robot to move 4 meters from one end to the other. The attached gripper used a 5/2 monostable valve to control the pneumatic actuators, followed by I/O signals from the robot to close/release the grip. MOTOMAN YRC1000 multi-axis and multi-tasking controller platform consisting of a Programming Pendant (PHG) was used to program the sorting process of the boxes.

Additionally, the development demonstrator does not consider the optimal sorting process with an optimal movement speed of box pick up and placement but instead showcases the ability to pick up the boxes placed on two different pallets and sort them into a full pallet. Furthermore, no priority on which boxes to pick up first was programmed. The simplified demonstrator has the pallets 180 mm distance from each other and only uses 4 boxes for demonstration. Boxes of with the height of 170 mm were used in demonstrator.

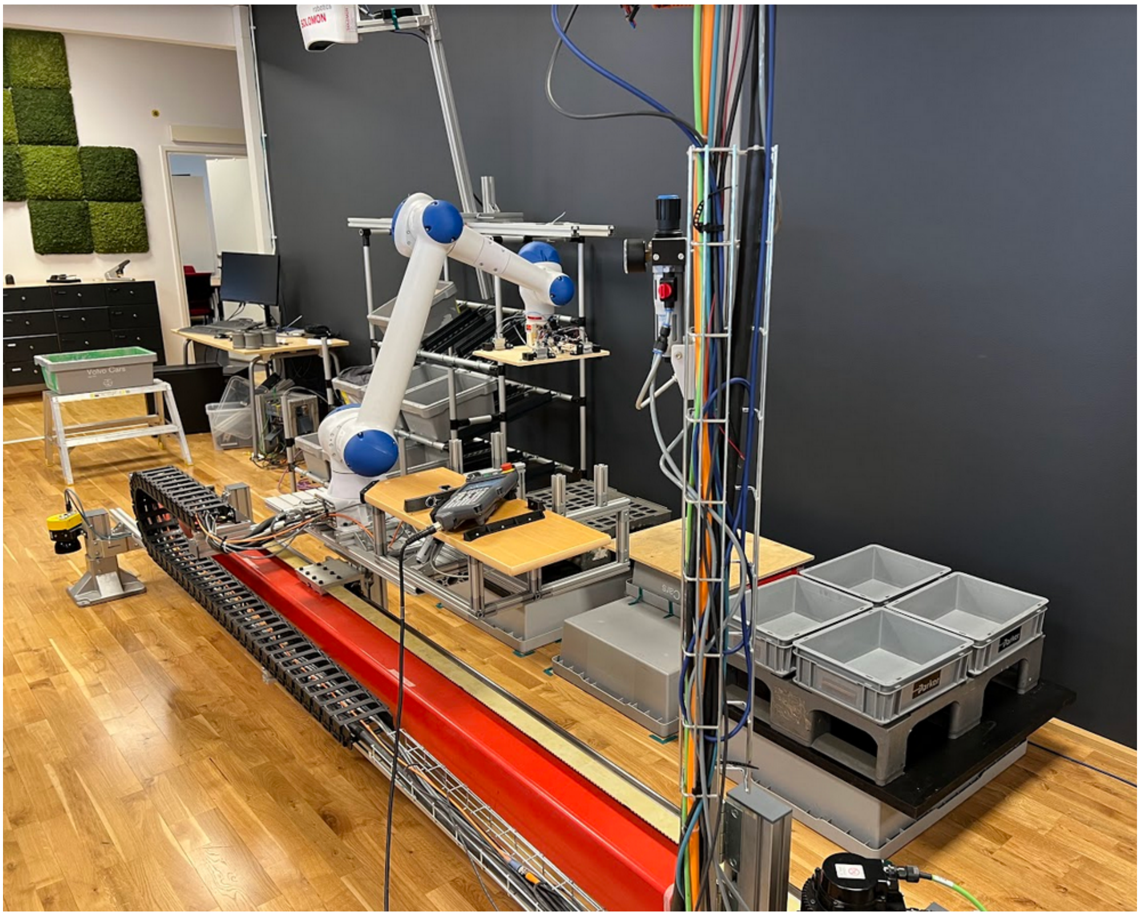

Figure 5.3: Yaskawa HC10 robot integrated with an external axis for linear translation

The sorting process of the boxes consisted of picking up the two unsorted boxes that are placed on each of the pallets, which were then placed on a empty pallet, see Figure 5.4 for illustration.

Figure 5.4: Starting location of the boxes

The robot was programmed to pick up two boxes individually from the pallet that had the boxes placed diagonally and then placed on the empty pallet. Robots' movements were programmed with the help of the Programming Pendant (PHG), and primary MoveLinear (MoveL) was used to move the robot. MoveL is used to move the tool centre point linearly to a specific pace at a certain speed. Move-Joint (MoveJ) was another programmed movement available in the PHG that does not consider the straight movement of the tool centre point but instead utilizes the movement of robots axes to a specific destination simultaneously. MoveJ was not used because it could have resulted in collisions with other objects.

The demonstrator showcased that the robot with an integrated linear unit could pick up the boxes from two different pallets and place them correctly on the empty pallet. During the picking processes of the boxes, it was noticed that the guided cones were of great help to compensate for robot inaccuracy. It highlighted its importance for the future concepts and implementation of this kind of solution; it is, therefore, vital to have a gripper that can compensate for robot inaccuracy and provide additional guidance for grasping.

As stated in the Case description there are around 80 pallets arriving from Bror Tonsjö every day that are supposed to go through the material handling. According to the times in Table 2.1 the calculated mean value for each activity for one pallet is the following in seconds:

Work Activity 1: Transport of material to goods department - 69.6
Work Activity 2: Scanning and labeling process - 164.4
Work Activity 3: Waiting for rear lift to be full - 159.0
Work Activity 4: Move materials to manufacturing (Torget) - 70.9
Work Activity 5: Lid removal processes - 15
Total mean value for all the activities combined: 478.9 seconds

It is worth noting that the time for Work Activity 3 according to Table 2.1 has a time of 660 seconds which distinguishes itself from the rest of the times which results in the mean value time for work activity 3 being high. In the material flow work activity 1, 2, 4 and 5 are performed manually by operators. The total mean time for these four activities is 319.9 seconds. By having to handle 80 pallets per day and the manual operating time for each pallet is 319.9 seconds the total manual operating time per day spend in the material flow is:

319.9 * 80 = 25 592 seconds which is around 7 hours and 6 minutes.

This means that 3 operators will have to spend around 2 hours and 21 minutes per day working within the material flow.

To be able to fulfil Parker Hannifin's KPI to have a higher fillrate of the pallets, the pallets that are delivered by Bror Tonsjö but are not completely full are therefore combined with each other. To estimate the new fillrate and the new total amount of pallets, some simplification were made. The simplification consisted of assuming that pallets only consisted of 4 boxes and not 8, due to the unknown factor of how many pallets that currently consists of 4 or 8 boxes.

The pallets that does not have a 100% fillrate are combined to increase the total fillrate. It is necessary to calculate the number of total pallets for each distribution to know how and which pallets are possible to be combined. A calculation of the new total number of pallets for each distribution and with 80 pallets used as reference to get the new fillrate; additionally for simplicity when calculating, the answers are rounded off to whole number. The current fullrate used as a reference can be seen in Figure 5.5:

Figure 5.5: Current fillrate of the pallets

To achieve a higher fillrate and reduce the number of pallets, the pallets that consist of only two boxes are combined, resulting in 7 full pallets with 4 boxes containing two different articles (Pallet B). The pallets that consist of only one full box are combined, which results in four full pallets containing four different articles(Pallet C) and two extra boxes (Box X) . These two extra boxes are placed on two of out the three pallets that have three boxes. This results in two pallets containing 4 boxes with 2 articles (Pallet D) and one pallet containing one article with an empty box (Pallet E).

This results in a total of 58 pallets. For illustration, see Figure 5.6. The same colors represent the same article. Pallet B has two different articles and Pallet C has four different articles for example.

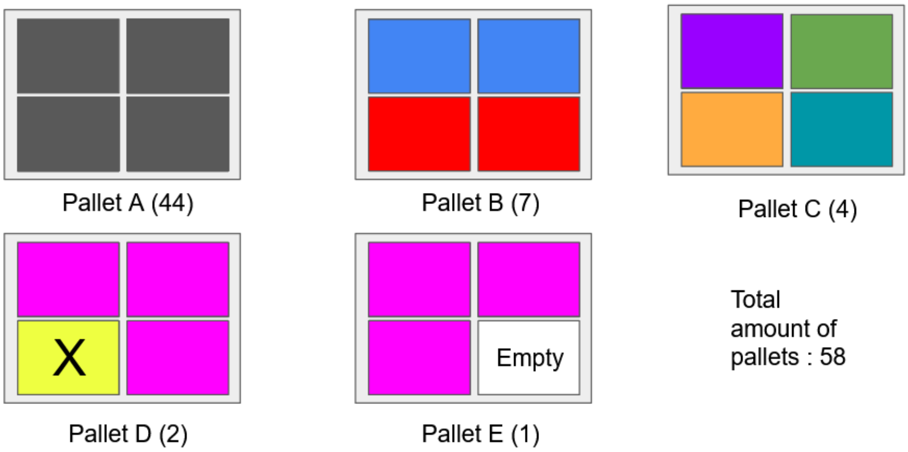

Figure 5.6: New estimated fillrate of the pallets

Total distribution in the concept solution

- 44 full pallets that have all boxes of the same articles.
- 7 full pallets that have two boxes of the same articles.
- 4 full pallets that have four different articles.
- 2 full pallets that have three boxes of the same articles and one different.
- 1 pallets that only has three boxes of the same article´and one empty box.

In the concept solution the work activities and estimated time mean value time in seconds for a pallet is the following:

Work activity 1: Get pallet from roller conveyor (Done by AMR) - 70
Work activity 2: Goods department, manual lid removal process - 15
Work activity 3: Transport to sorting area (Done by AMR) - 30
Work activity 4: Sorting process (Robot) - 50
Work activity 5: Move material to manufacturing Torget (Done by AMR) - 70
Total mean value for all the activities combined: 235

In the concept solution we have estimated the time based on the times of the current transport and assumed that the AMR moves with roughly the same speed as the operators do with the power tracker and rear lift. The sorting area and sorting process are assumed to be within 5 meters of each other when doing the time calculation, most of the time in this process is picking up and placing down the pallet. The time of the lid removal process is estimated based on work activity 5 in the current state and is estimated to be 15 seconds in both cases. The time of the sorting process is based on the times measured in the demonstrator and it is estimated that it takes 25 seconds to move one box from a pallet to another and that two boxes needs to be moved on to a pallet to fill it.

In the concept solution only work activity 2 which is the lid removal process is done manually by the operators. With the estimated amount of pallets incoming with the new fillrate and the estimated time for the lid removal process the total manual operating time is:

58*15 seconds which is around 15 minutes.

This means that 1 operator can be used and spend around 30-45 minutes per day working with the material flow. This estimation is done based on the total amount of time needed to remove the lid, travel time between pallets and returning lids to storage. This means that the operator will spend less than 1 minute of manual working time on each pallet every day.

With these calculations the material flow process improves in the three KPIs, lead time, manhours and fillrate by the following amount in seconds per pallet:

Lead Time Current: 479
Lead time Concept: 235
Lead Time Improvement: 244
Manhours Current: 320
Manhours Concept: 60
Manhours Improvement: 260
Fillrate current: 80 Pallets, See Figure 5.5
Fillrate Concept: 58 Pallets, See Figure 5.6
Fillrate Improvement: 22 Pallets less

The new material flow in the concept solution will have a lead time of 235 seconds which includes up to 60 seconds of manual labor. Instead of 80 pallets arriving daily 58 pallets will arrive increasing the fillrate on these pallets and reducing the amount of pallets by 22 that the operators need to handle each day. This also means that the AMR and Robot will have less pallets to handle and the total transport time will be lowered. For a complete view of the concept material flow see Figure 5.7 below:

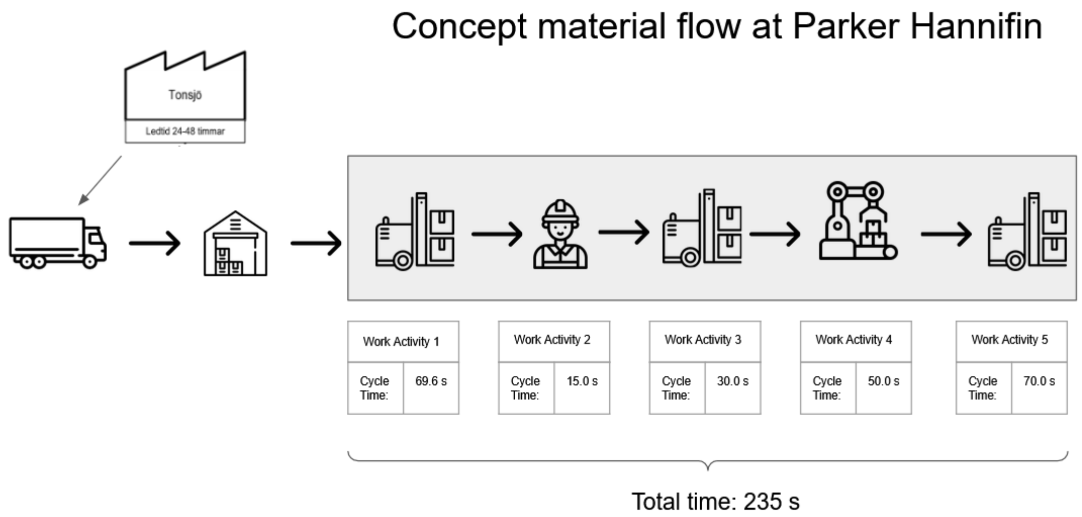

Figure 5.7: Concept material flow

6
Discussion

In this chapter problems in the project, limitations and future possibilities are discussed. There are several limitations to this concept solution and some simplifications were made in the demonstrator. It is also important to highlight the future benefit and opportunities that can come as a result of this thesis.

6.1 Theoretical contribution

This thesis further contributed to research about automation within material handling, where a company's situation, in this case, Parker Hannifin's material handling flow, was used to analyze and develop a demonstrator to showcase the possibilities of implementing automation. It was noticed that an integrated control system, such as IoT, for data transfer between different automated solutions is necessary. As seen in the literature and the results from this thesis, IoT is a necessary technology when integrating, i.e., RFID-system, automated guided vehicles, and the robot is required. It was also noticed that robot inaccuracy plays a huge role when robot picking is implemented. As highlighted in the literature the problem that the robot needs to know the exactly location of the object that needs to be picked up became obvious. In the literature a vision system or a fixture is a common solution for this problem. Another solution for robot inaccuracy that was discovered in literature was design of a gripper that could self align and compensate for the inaccuracy [23]. In our case, the easiest solution became to design and develop a gripper due to the complexity and required time to build proper fixtures.

This thesis showcases companies in similar situations as Parker Hannifin's, where manual labor is a big part of material handling flow, the possibilities of automation, and their application. It can guide companies on what kind of automation can be implemented and what technologies are necessary. This thesis also shows the potential automation implementation could have on material flow, such as the increase in fillrate by combing different articles to each other, reduction of the total amount manual labor spend in material flow and removal of manual labor tasks.

6.2 Prerequisites for implementation of the concept solution

For the concept solution to work properly there are some limitations regarding the material handling case and there are certain factors that needs to be accounted for. These limitations had an impact on the demonstrator and how it was built but also gave us an overview of what the obstacles of implementation this solution might be.

One of the most obvious limitations is the transfer of information from the individual pallets/boxes to the sorting robot. The robot has to know which box contains what and also exactly where it is placed to be able to pick it up. This requires a transfer of both content and placement information to the robot. The robot relies entirely on this information to perform its work and if wrong information is sent to the robot it can cause the sorting process to fail or make the robot crash. Errors can occur in the sorting process if the robot receives wrong information and can cause pallets to receive the wrong articles. It is up to the operators in the manufacturing process to confirm that the correct material is received and sent to processing.
The information has to be sent to the robot either automatically via an RFID-system or manually by an operator. In the case of the automated information transfer such a system has to be set up and be working correctly as well along with the sorting robot. Additional time and effort needs to be spend to have a working information transfer system as well for a success full implementation of the concept solution.

Another limitation is the amount of different products/articles that are being handled within the material flow. The Yaskawa HC-10 has a limitation of working area by being limited in working distance or reach distance and even if the robot would have an "endless" reach the sorting process would also be limited by available space. The pallets Parker Hannifin uses are 800x600mm and if standard EU-pallets are used (1200x800mm) the pallets will require even more space limiting the amount of different articles/items that can be handled by the sorting process. The robot could also possible reach and being able to sort on a lot of pallets but since the robot itself cannot move these there also need to be room for another source (AMR/Manual) to move and replace the pallets as they are sorted. This limits the distance between the pallets as the source needs to be able to properly pick up and move the pallets.

For the demonstrator a gripper was developed to be able to pick up the boxes from the pallets. The gripper in the demonstrator utilized the holes made for the lid on the boxes to be able to pick them up. Every box in the material flow needs to have these holes for the robot to be able to pick them up. If the material flow contains boxes without holes they either needs to be replaced or another gripper able to pick up the boxes needs to be developed. This gripper also needs to be able to handle the load of the box and also handle uneven loads in case the boxes are not loaded with even distributed weight. The demonstrator used a gripper made of wood and plastic, this was used to pick up empty boxes and will not be sturdy enough to handle the weight from boxes with a weight upwards of 25kg or more. If a similar design of the gripper used in the demonstrator is used it needs to be be handle a higher load, this means that if the wood and plastic is removed another type of pneumatic motor could also be required to handle the assumed extra weight of the gripper.

6.3 Larger demonstrator

The demonstrator tested the most important and central function of the concept solution, which, as previously mentioned, is the sorting process. The sorting process is the most essential and central function of the concept solution because it helps to increase the fillrate by sorting the boxes and reduces the amount of man-hours in the material handling flow. One essential test and evaluation was done when programming the grasping function with the help of a Phrogramming Pendant (PHG). The grippers grasping function was tested and showcased the importance of the design of the gripper. Grippers-guided cones that were developed thanks to consultation with laboratory technicians compensated for the robot inaccuracy. The demonstrator provided vital information about the concept solution's central and most significant process. It showed that the concept's solution central process works and the importance of having a gripper that can self-align and compensate for robot inaccuracy. Robots control and linear translation showed the Yaskawa HC-10 robot's ability to sort the boxes and place them correctly on the empty pallet.

Literature study and consultation with the laboratory technicians helped develop and implement the central function of the concept solution. The developed gripper had a significant impact on the demonstrator. The demonstrator further strengthens the value of the concept solution by demonstrating a fully working sorting process developed in the laboratory, where unsorted boxes can be picked up and placed on an empty pallet. With the data gathered from testing and evaluating the demonstrator, could the last research question be answered. The demonstrator helped to better understand how most essential and central function of the concept solution worked in reality. The concept solution further benefits the demonstrator by showing that it works, which provides value, and showcases the possibilities and opportunities for Parker Hannifin.

6.4 Benefits for Parker Hannifin

By showcasing the concept solution along with the benefits and obstacles with implementation to Parker Hannifin it can give a broad idea of the general requirements and positive aspects when deciding to invest in similar new technology. Many of the benefits and obstacles are general to implementation of automated solution and can be considered regardless of which automated solution that is being implemented. By giving Parker Hannifin a detailed view of the possible processes to automate, motivating why, and showing the potential improvements in the KPIs mentioned in Chapter 3.5 Parker Hannifin can get a detailed view on what results such an implementation would yield.

The exact concept solution does not have to be implemented for Parker Hannifin to gain value from this project. A similar solution could be implemented using the knowledge and working process used in this thesis. Parker Hannifin could also use the knowledge and information gained in this project when decided to implement automation as a solution to handle different material handling processes or any process in general that are within the limitation discussed in this chapter. One important factor to highlight is that while this thesis and project are directly aimed at the material handling within Parker Hannifin and the F11 and F12 axles product groups the same method of working can be applied to other projects. This method of identifying potentials and then working towards improvements of KPIs could be used in many different scenarios.

As stated in Chapter 4.3 automation is a common solution to handle transport of materials and logistics for companies. Automated solutions could benefit Parker Hannifin by working in collaboration with suppliers to increase the benefits. Automated solutions does not have to be implemented at Parker Hannifin to benefit them as another company could implement automation and having it benefit Parker Hannifin. As an example if automation would be implemented at Bror Tonsjö within the process of unloading it will benefit Parker Hannifin in the terms that the delivery truck no longer will require manual labor in the form of truck drivers to manually move the pallets from the truck to the storage area within the Parker Hannifin factory. Automation could as such be implemented by suppliers in collaboration with Parker Hannifin and having it benefit both companies. This also makes the work in this thesis not only important and beneficial to Parker Hannifin themselves but also companies which collaborations with them.

It is also worth noting that while implementing automation to reduce the man-hours within the material flow does reduce the amount of operators needed to perform manual work there still will be a need of operators. As an example implementing the automated solution could remove the need for six operators to work within the material flow but instead create the need for two mechanics to perform maintenance work on the AMR and robot respectively. The benefit for Parker Hannifin will be that the operators are reduced by six but will require the hiring of two mechanic instead. Automation usually does not just "remove" the need for operators it rather reduces the amount needed and requires the operators to have a different skill set to cope with the new technology. It is important as an investor that while the overall cost might be reduced new competence might need to be added to the workforce in order for the new technology to work properly.

6.5 Future opportunities

In the future this type of solution with automated transport and sorting can be used in multiple scenarios not just at Parker Hannifin but also other companies as mentioned above. It can be suitable for any type of company with a similar problem as Parker Hannifin that wants to eliminate manual work, increase productivity and handle any type of sorting process. The concept solution is flexible and multiple things can be changed depending on what type of work or other limitations that other material flows or companies have. Any company that wants to eliminate manual transport can benefit from having it automated by a AMR. The AMR can be chosen depending on available space and size of the material that needs transport and are not exclusive to only material handling and can be used to transport any type of material. The AMR does not need to be able to pick up the material itself as this can be done manually but the transport is then done by the AMR. This can be beneficial if the transport distance is very long removing the need for an operator to spend time transporting material.

The sorting robot could be used in any type of scenario where sorting of articles is needed and depending on what type of material that is being sorted a different gripper could be attached to the robot allowing it to pick up other materials than just boxes. As stated before a smaller or larger robot could be used depending on each individual scenario but the size of both robot and gripper are flexible choices. Having a robot with a custom gripper could also allow it to pick 2 different components and present them for assembly as an example of use in a different area. In the case of the sorting robot an information flow needs to be connected to it. This could be done automatically or manually but it is a mandatory pre-requisite for this type of automated solution to work.

For having a successful implementation of the concept solution Parker Hannifin needs to adress a few things. The first is to have a working RFID-system in place that can send content and location information to both the AMR and robot. This information flow also needs to be connected to the manufacturing area at Torget as prioritized sorting is a key feature of the concept solution. The choice of which AMR, robot and gripper to use is also something that Parker Hannifin needs to adress in the future to have the best possible fit for this type of material handling.

Parker Hannifin could also choose to implement only one of the suggested automated solutions. The concept solution would need to be altered but still benefits can be achieved by only implementing the automated transport by AMR for example as it will reduce the amount of time the operators need to move material. By doing this Parker Hannifin could have the AMR perform the transport of material with the same fillrate unchanged and the operators performing the lid removal process. Since the amount of pallets will still be the same the operators would spend equal amounts of time removing the lid but will have the working time of transporting material removed.

6.6 Economics and sustainability

Due to the increased fillrate, investing in automation improves the sustainability within the material handling flow and in turn reduces the amount of pallets that need to be transported within factory. It is also important to highlight that the amount of incoming material still stays the same, but pallets are just more effectively utilized thanks to combining different articles with each other. Less pallets will also need to be transported to the factory, smaller trucks with lower emissions could be used. Here it it also important to note just as within the material flow, that the amount of material stays the same but can be packaged and use a smaller area when transported.

Automation solutions are often better and can provide a lower running cost compared to manual work. However they usually require a high investment cost as the technology is very expensive. In the concept solution it is estimated that the robot used for sorting will have a higher investment cost than the AMR. To implement automation in general a substantial investment needs to be made and the return on investment can take years. Automation is usually not a short-term solution and is more often seen as an investment for the distant future. This is something Parker Hannifin need to further analyze to choose the most appropriate solution.

7

Conclusion

Currently, Parker Hannifin has a material handling flow involving a substantial amount of manual work that includes scanning and labeling boxes and transporting materials from the delivery storage to the correct places within the factory. Parker Hannifin wants to investigate the potential of implementing automation within their material handling flow. This thesis has focused on identifying suitable processes within material handling that have the greatest impact on material flow performance.

To address the problem, we performed literature research and data collection, including direct observation, time studies, and informal interviews with employees at Parker Hannifin to identify which material handling processes that held potential for the application of automation. Additional consultation with members of the SCARCE II project and laboratory technicians also provided guidance in the project. After identifying the potential improvement areas for automation, different automated solutions were weighed against each other with the help of a Pugh-matrix to ensure the solution brought the most significant impact. In the laboratory, a demonstrator was built with the available resources to demonstrate the potential of this concept.

The demonstrator results showed that the concept solution is a realistic investment and could improve the material handling flow at Parker Hannifin. According to the results of the demonstrator, in comparison to the current material handling flow, the concept solution will increase the fillrate by combining articles which will reduce the total amount of incoming pallets. It will also reduce the amount of man-hours needed in the material handling flow and reduce the total lead time by removing manual scanning and labeling with the help of RFID.

The concept solution consists of an AMR handling the transport between delivery storage, a sorting robot and Torget, and a robot sorting the pallets containing mixed articles into pallets containing only one article. There is also the need for an integrated control system to handle the information transfer between the RFID, AMR, robot, and manufacturing.

Parker Hannifin receives valuable information regarding an automation implementation process and the general obstacles and potentials with such an investment. Other companies with similar processes or situations could also benefit from this thesis work by using the information provided and evaluating their processes for potential improvements.

Bibliography

[1] J. Green, J. Lee, and T. Kozman, "Managing lean manufacturing in material handling operations," *International Journal of Production Research*, vol. 48, pp. 2975–2993, 05 2010, doi 10.1080/00207540902791819.

[2] M. P. Stephens, *Manufacturing facilities design and material handling*, sixth edition ed. West Lafayette, Indiana: Purdue University Press, 2019.

[3] M. Hassan, "A framework for selection of material handling equipment in manufacturing and logistics facilities," *Journal of Manufacturing Technology Management*, vol. 21, pp. 246–268, 02 2010, doi 10.1108/17410381011014396.

[4] E. Lindström, "Fördelarna med automatiserad logistik och materialhantering," https://blog.toyota-forklifts.se/fordelarna-med-automatiserad-logistik-och-materialhantering, accessed: 2022-03-01.

[5] J. M. Ashutosh Dekhne, Greg Hastings and F. Neuhaus, "Automation in logistics: Big opportunity, bigger uncertainty," https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/automation-in-logistics-big-opportunity-bigger-uncertainty, accessed: 2022-03-01.

[6] M. Emiliani and D. Stec, "Leaders lost in transformation," *Leadership Organization Development Journal*, vol. 26, pp. 370–387, 07 2005, doi 10.1108/01437730510607862.

[7] B. Glover, *RFID essentials*, 1st ed. O'Reilly, 2007. [Online]. Available: https://r4.vlereader.com/Reader?ean=9780596514792

[8] M. Bolic, D. Simplot-Ryl, and I. Stojmenovic, *RFID Systems*, 1st ed. John Wiley Sons, Incorporated, 2010. [Online]. Available: https://ebookcentral.proquest.com/lib/chalmers/reader.action?docID=555052

[9] A. Khattab, Z. Jeddi, E. Amini, and M. Bayoumi, *RFID Security*, 1st ed. Springer Internatinal Publishing AG, 2017. [Online]. Available: https://link-springer-com.proxy.lib.chalmers.se/content/pdf/10.1007%2F978-3-319-47545-5.pdf

[10] M. Hermann, T. Pentek, and B. Otto, "Design principles for industrie 4.0 scenarios," in *2016 49th Hawaii International Conference on System Sciences (HICSS)*, 2016, pp. 3928–3937.

[11] O. Efthymiou and S. T. Ponis, "Current status of industry 4.0 in material handling automation and in-house logistics," *International Journal of Industrial and Manufacturing Engineering*, vol. 13, no. 10, pp. 1382 – 1386, 2019. [Online]. Available: https://publications.waset.org/vol/154

[12] J. Wan, S. Tang, Q. Hua, D. Li, C. Liu, and J. Lloret, “Context-aware cloud robotics for material handling in cognitive industrial internet of things,” *IEEE Internet of Things Journal*, vol. 5, no. 4, pp. 2272–2281, 2018.

[13] M. G. P. P. Nurul Huda Mahmood, Nikolaj Marchenko, *Wireless Networks and Industrial IoT*, 1st ed. Springer Cham, 2021, doi https://doi.org/10.1007/978-3-030-51473-0.

[14] C. Cronin, A. Conway, A. Awasthi, and J. Walsh, “Flexible manufacturing using automated material handling and autonomous intelligent vehicles,” in *2020 31st Irish Signals and Systems Conference (ISSC)*, 2020, pp. 1–6, doi 10.1109/ISSC49989.2020.9180172.

[15] S. Ponis and O. Efthymiou, “Cloud and iot applications in material handling automation and intralogistics,” *Logistics*, vol. 4, p. 22, 09 2020, doi 10.3390/logistics4030022.

[16] N. Horň, Luká, L. Jurík, H. Hrablik, D. Cagá, and D. Babčanová, “Ahp method application in selection of appropriate material handling equipment in selected industrial enterprise,” *Wireless Networks*, 06 2019, doi 10.1007/s11276-019-02050-2.

[17] “Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda,” *European Journal of Operational Research*, vol. 294, no. 2, pp. 405–426, 2021, doi https://doi.org/10.1016/j.ejor.2021.01.019.

[18] G. Ullrich, *Automated Guided Vehicle Systems*, 1st ed. Springer, Berlin, Heidelberg, 2015, doi https://doi-org.proxy.lib.chalmers.se/10.1007/978-3-662-44814-4.

[19] Toyota, “Flexibel logistik med automationslösningar,” https://toyota-forklifts.se/automation/automatiserade-losningar/, accessed: 2022-03-25.

[20] R. Patricio and A. Mendes, “Consumption patterns and the advent of automated guided vehicles, and the trends for automated guided vehicles,” *Current Robotics Reports*, vol. 1, 09 2020, doi 10.1007/s43154-020-00007-4.

[21] S. Kaliappan, J. Lokesh, P. Mahaneesh, and M. Siva, “Mechanical design and analysis of agv for cost reduction of material handling in automobile industries,” *Int. Res. J. Automot. Technol*, vol. 1, no. 1, pp. 1–7, 2018.

[22] M. I. Robots, “Agv vs. amr - what’s the difference?” https://www.mobile-industrial-robots.com/insights/get-started-with-amrs/agv-vs-amr-whats-the-difference/, accessed: 2022-03-26.

[23] G. Causey and R. Quinn, “Gripper design guidelines for modular manufacturing,” in *Proceedings. 1998 IEEE International Conference on Robotics and Automation (Cat. No.98CH36146)*, vol. 2, 1998, pp. 1453–1458 vol.2, doe 10.1109/ROBOT.1998.677309.

[24] G. Carbone, *Grasping in Robotics*, 1st ed. Springer, London, 2013, doi https://doi.org/10.1007/978-1-4471-4664-3.

[25] D. Parmenter, *Key Performance Indicators (KPI) : Developing, Implementing, and Using Winning KPIs*, 2nd ed. John Wiley Sons, Incorporated, 2010. [Online]. Available: https://ebookcentral.proquest.com/lib/chalmers/detail.action?docID=485633

[26] V. J. Andrej Rakar, Sebastian Zorzut, “Assesment of production performance by means of kpi.”
[27] S.-A. M. Patrik Jonsson, *Manufacturing Planning And Control*, 1st ed. Maidfenhead, Berkshire: McGraw-Hill, 2009.
[28] R. M. Y. E. O. B.-S. Keren Kapach, Erud Barnea, “Computer vision for fruit harvesting robots – state of the art and challenges ahead,” *Int. J. Computational Vision and Robotics*, vol. 3, 2012.
[29] R. K. Yin, *Case Study Research and Applications*, 6th ed. SAGE Publications Inc, 2018.

A

Appendix 1

Figure A.1: Roller conveyors where the pallets are delivered

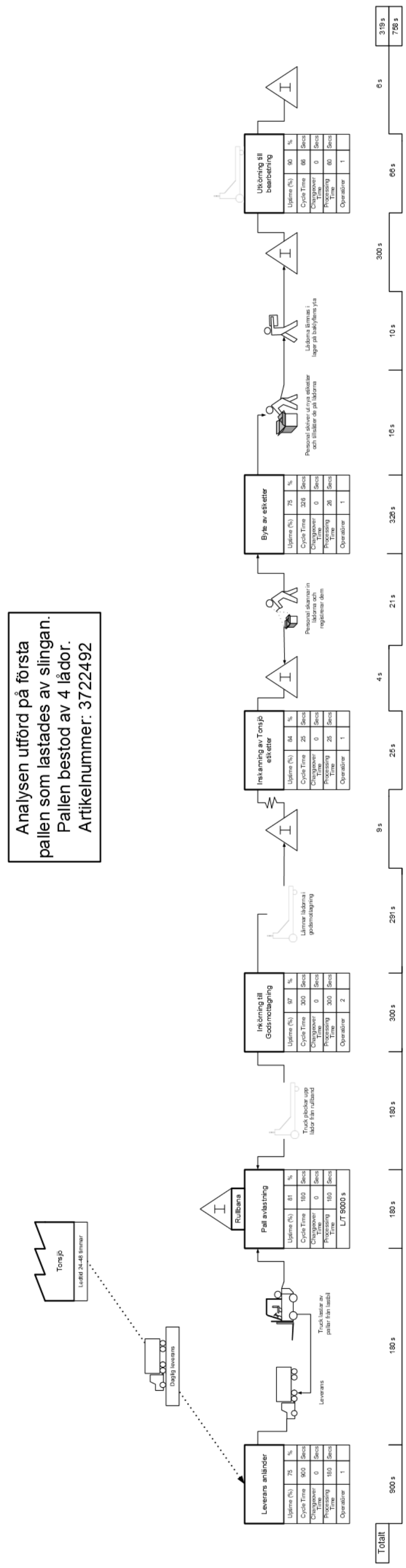

Figure A.2: Value stream from KTH

Figure A.3: Location of the holes for grasping

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